Xiaomin Lin | Research Statement

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As a roboticist emerging from an active perception lab, my research ambitiously designs tangible autonomous robotic systems with robust perception capabilities, with a special emphasis on sustainability and conservation. In my view, robotics and perception are highly intertwined: for robots to perceive and interact effectively with their surroundings, they must understand when, what, and where to perceive. However, the computational and power demands of current trends, such as large language models, pose a challenge in robotics, where efficiency and ***frugality*** are crucial, especially in resource-limited marine environments.

In response to the recent trends and constraints, my work prioritizes developing ***Frugal Robots (FRUBOTS)***—robots that integrate perception and decision-making with minimal energy consumption and computational overhead while achieving their objectives. By incorporating edge computing and active perception, ***FRUBOTS*** can operate sustainably and independently in diverse ecosystems, from marine habitats to agricultural landscapes, supporting large-scale environmental monitoring without excessive resource demands.

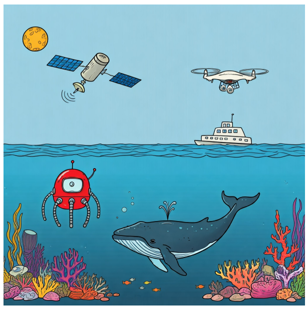


Fig. 1 Monitoring from Satellite[1], [2], to aerial[3], [4] to ocean surface to underwater[5]–[7]. Image generated by Xiaomin.

This focus on resource-efficient robotics has been strengthened by my experience assisting Prof. Yiannis Aloimonos in crafting **NSF Foundational Research in Robotics (FRR) proposals**, where I gained valuable insights into aligning innovative research with funding priorities. Building on this foundation, my collaboration experience with Prof. Jane Shine (University of Florida) and Prof. Yiannis Aloimonos on an **ONR proposal for the Science of Autonomy**, advancing adaptive underwater sensing to tackle pressing environmental challenges. Beyond this, I am also collaborating with Prof. Doingyi Wang (University of Arkansas) on a **USDA Agriculture and Food Research Initiative (AFRI) proposal** aimed at enhancing agricultural practices for chicken farms, broadening the application of FRUBOTS to improve sustainability across domains.

Frugality in Edge Perception and Planning

Long-term environmental monitoring through autonomous systems requires not only advanced navigation and data collection capabilities but also a commitment to resource-efficient and frugality design in the perception system. This approach has two key aspects: first, building lightweight networks and algorithms that can operate on edge devices; and second, incorporating frugality into decision-making processes.

Algorithms— My work centers on designing algorithms that enable robots to monitor and adapt to environmental conditions directly on edge devices [5], [7], [8]. By leveraging edge computing [7], [8], these systems process data locally, allowing for immediate, on-the-spot analysis, which reduces reliance on remote data transmission and enhances autonomy. For example, we [9] have developed a lightweight network architecture for water-surface segmentation that runs efficiently on a CPU, enabling these robots to operate independently across diverse ecosystems, from underwater reefs to forested terrains.

Fig. 2 A hexapedal robot with edging computing on board, detecting oysters. Image from Xiaomin.

Optimal Decision-Making— The idea of frugality is deeply embodied within active perception which is central to my work. As demonstrated in ViewActive [10], where a robot images the aspect graph (view quality) and selects optimal viewpoints for object recognition with minimal movement. Similarly, UIVNAV [11] integrates human-inspired actions to plan efficient exploration paths in underwater environments. This frugal design approach enables FRUBOTS to deliver scalable environmental monitoring and data collection solutions, advancing sustainable practices through resource-efficient autonomy.

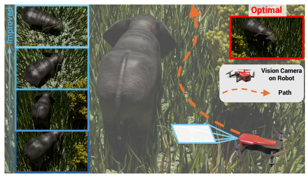
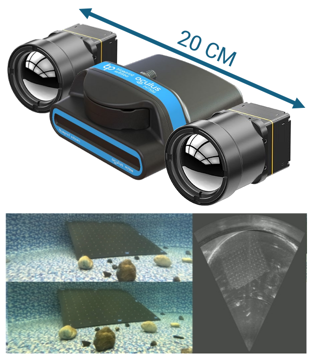


Fig. 3 A drone selecting the optimal viewpoint[10] for object detection. Image from Xiaomin.

Future Research Vision While large language models (LLMs) offer strong reasoning capabilities, their high computational demands limit edge deployment in resource-constrained settings. Future systems must emphasize lightweight networks, active perception, and small, efficient models for edge devices. Resource-aware frameworks will enable FRUBOTS to adapt strategies dynamically, integrating on-device processing for rapid, localized decisions. These innovations support ecosystem conservation, improve aquaculture, and enhance safety in underwater operations, addressing societal challenges like climate change and marine industry innovation.
To advance these works, I will be seeking funding from agencies such as the **NSF CAREER, Robust Intelligence programs(CISE/IIS), and Foundational Research in Robotics(FRR)** for research in robust, adaptive AI systems, as well as **Department of Energy, Advanced Research Projects Agency– Energy(ARPA-E)** for research in resource-efficient robotics systems.

Frugality in Multimodal Perception

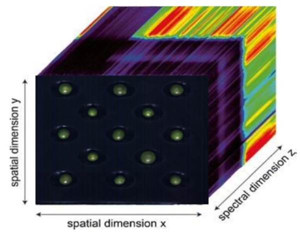
In complex environments, multimodal perception integrates data from sources such as optical-acoustic, optical-infrared, drone-satellite, and multispectral imaging, overcoming single-sensor limitations to provide comprehensive insights with improved efficiency and sustainability.
Opti-Acoustic Imaging— To enable resource-efficient operation in low-visibility underwater environments, I plan to develop a sensor that combines optical and acoustic data. By integrating the high resolution of optical imaging with the penetrative capabilities of acoustic sonar, this approach balances clarity with efficiency. Early work [12], [13] demonstrates that merging these modalities improves object detection and 3D reconstruction accuracy, offering robust solutions for complex aquatic monitoring tasks. Another key focus is developing efficient, resource-aware frameworks that enable FRUBOTS to dynamically adapt sensory modalities and processing strategies based on specific tasks and conditions. For example, FRUBOTS could use sonar for low-visibility navigation and RGB for close-range detail, employing adaptive data fusion to optimize energy efficiency and precision.



Stereo Opti-Acoustic Sensor on the top. Stereo Opti-Acoustic image([12]) as illustrated below. Sonar Source, Camera image from Source.

Future Research Vision An adaptive "multimodal underwater imaging model" is essential to further this work. This model will selectively prioritize optical and acoustic data based on task demands to conserve power while integrating these modalities to deliver comprehensive, real-time ecosystem views. This adaptive model will enhance sustainable underwater monitoring, supporting ecosystem conservation, climate resilience, and advancements in precision aquacultural.
To advance this vision, I plan to seek funding from the **Office of Naval Research (ONR)** for innovations in underwater sensing, **NOAA**for marine exploration grants, and **SERDP** for environmental resilience research.

Multispectral Imaging— Multispectral imaging enables precise, frugal agricultural monitoring by adapting sampling to specific spectral bands that reveal critical crop characteristics. In berry detection, for example, our multispectral approach focuses on wavelengths that best capture vegetation health and berry quality, significantly reducing data processing needs. As shown in the accompanying image, this technique optimizes grape yield and quality assessments, aligning with sustainable, resource-efficient practices.



MultiSpectral Imaging with sonar. Source

Future Research Vision Future research will focus on further refining adaptive multispectral sampling for dynamic selection of spectral bands based on crop type, growth stage, and conditions, enhancing precision and efficiency. Funding opportunities include the **USDA Agriculture and Food Research Initiative (AFRI)**, **NASA's Applied Sciences Program**, and the **NSF's Division of Environmental Biology (DEB)** to support sustainable resource management through advanced sensing technologies.

Frugality in Data Collection/Generation

In challenging environments like underwater ecosystems and remote sensing applications, traditional data collection is often labor-intensive and costly. Synthetic data that accurately simulates real-world conditions offers a frugal, scalable alternative, enabling advanced systems with fewer resources.

Agricutural/Aquacutural— I have developed drone-based methods for olive yield estimation [3], a complex task due to foliage density. In aquaculture, I collaborate with the Maryland and Delaware Departments of Natural Resources on annual oyster stock assessments [5], [7]. My goal is to empower farmers and resource managers with frugal AI-driven tools for yield estimation and resource planning, advancing sustainable practices and efficient resource use.

Real images on the left with synthetically generated images on the right. From the first row to the last are whales[1], the BlueROV robot[4], oysters underwater[5], and olives[3].

Future Research Vision This research aligns with funding from **NASA's Aeronautics Research Mission Directorate (ARMD)** for sustainable autonomous systems, and several **USDA programs** like the **Agriculture and Food Research Initiative (AFRI)**, **Sustainable Agriculture Research and Education (SARE)**, and **Conservation Innovation Grants (CIG)**, all focused on precision agriculture and sustainable resource management.

Very High Resolution(VHR) Satellite Imagery— VHR imagery offers a frugal approach to conservation by providing scalable, precise wildlife monitoring in remote areas, supporting global biodiversity goals like UN Sustainable Development Goal(SDG) 15. Leveraging this technology with synthetic data and advanced models enables effective, resource-efficient monitoring for both marine [1], [2] and terrestrial ecosystems [14], [15]. This approach enhances data accuracy and accessibility, empowering biologists and decision-makers to make informed, impactful decisions with minimal field resources.

Future Research Vision Future developments will focus on refining VHR and synthetic data integration to maximize monitoring precision across diverse habitats. Funding from **NASA's Earth Science Division (ESD)**, **NOAA**, and the **US Geological Survey (USGS)** will support scalable conservation technologies. The **NSF**, particularly its DEB and LTER programs, offers further support for advancing frugal, AI-driven conservation monitoring solutions.

Next Step

My research centers on advancing autonomous robotic systems equipped with robust perception capabilities to address critical environmental monitoring needs. With a focus on frugality, I aim to maximize efficiency through lightweight networks and optimal decision-making algorithms that can operate on edge devices, reducing dependency on high-power computational resources. This approach enables robots to function independently in resource-limited environments, such as underwater ecosystems and remote agricultural settings, supporting ecosystem conservation, improving aquaculture practices, and enhancing safety in critical operations while addressing societal challenges like climate resilience and sustainable innovation.

In multimodal perception, I plan to come up with a new sensor and algorithm design that integrates various sensing modalities, such as optical, acoustic, and multispectral imaging, to enhance decision-making, detection, and navigation. Synthetic data generation plays a significant role in my work by reducing the need for extensive field data collection, which is often labor-intensive and costly in challenging environments. This approach enables precise and sustainable monitoring in applications such as agriculture, aquaculture, and remote sensing. By improving data accuracy and accessibility, it empowers biologists and decision-makers to make informed, impactful decisions, supporting ecosystem conservation, climate resilience, and advancements in precision aquaculture with minimal resource demands.

I thrive in collaborative and interdisciplinary research environments, working with experts across fields to broaden the impact of my work. My collaborations include leaders in marine robotics, such as Prof. Shahriar Negahdaripour(Miami University), Prof. Ioannis Rekleitis(University of South Carolina), Prof. Herbert Tanner(University of Delaware), Dr. Nare Karapetyan(Assistant Scientist in WHOI), and Prof. Jane Shine(University of Florida). I have had a fantastic opportunity to collaborate with experts from various fields worldwide such as biologist Dr. Isla Duporge(Princeton), AI researcher Prof. Olga Isupova(University of Bath), computer scientist Prof. Michail G. Lagoudakis(Technical University of Crete), computer scientist Prof. Markus Vincze(Technical University Wien (TUW)), and biological and agricultural researcher Prof. Dongyi Wang(University of Arkansas).

I also have had the honor to work with the experts in Maryland, such as ecophysiologist Prof. Matthew Gray(University of Maryland Center for Environment Science(UMCES)), aquaculture specialist Mr. Don Webster(UMCES), aerospace engineering expert Prof. David Akin, mechanical engineer and researcher Prof. Miao Yu(University of Maryland), Prof. Nikhil Chopra(University of Maryland), robotist Prof. Pratap Tokekar(University of Maryland), neuromorphic scientist Dr. Cornelia Fermüller, and ecologist Dr. Jason E. Spires(NOAA Cooperative Oxford Laboratory). Taking initiative is key to my work; for example, at the 2024 Autonomous Systems Bootcamp, I led a team from eight institutions and companies, culminating in our joint publication on the Odyssee project[7] as the lead and corresponding author.

My work focuses on developing perception-driven, adaptive systems that interact intelligently within dynamic environments, advancing robotics, computer vision, and autonomous decision-making in ways that address critical real-world applications. With expertise in robotics and computer vision, I am especially excited about the opportunity to contribute to your esteemed university on FRUBOTS. These systems have the potential to revolutionize transformative areas such as embodied AI, where robots and intelligent systems seamlessly interact with the physical world, and foundational AI, where innovations in efficient, resource-aware models can drive advancements across domains like environmental monitoring, agriculture, and autonomous exploration. By integrating cutting-edge research with practical applications, I aim to contribute meaningfully to both academic excellence and societal impact.

Appendix

Many of our projects release open-source code and data to enable the academic community to validate and build upon our work, just as we benefit from others' shared contributions. Below is a selection of these resources:

Underwater Simulation for Oyster Reef Monitoring, Dataset for Oyster Detection and synthetic oysters [5], [6]. https://github.com/prgumd/Oystersim

Motion & Geometry Aware Real and Virtual Image Segmentation[9] https://prg.cs.umd.edu/MARVIS

Synthetic VHR Satellite Data Generation for Whale Detection[1] https://github.com/prgumd/SeaDroneSim2

Synthetic Aerial Image generation for Maritime Object Detection[4] https://github.com/prgumd/SeaDroneSim

Viewactive: Active viewpoint optimization from a single image, [10] https://github.com/jiayi-wu-umd/ViewActive

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