CPS: Synergy: Collaborative Research: LEAR-CPS: Low-Energy computing for Autonomous mobile Robotic CPS: A Hardware-and-Algorithms Co-design Approach

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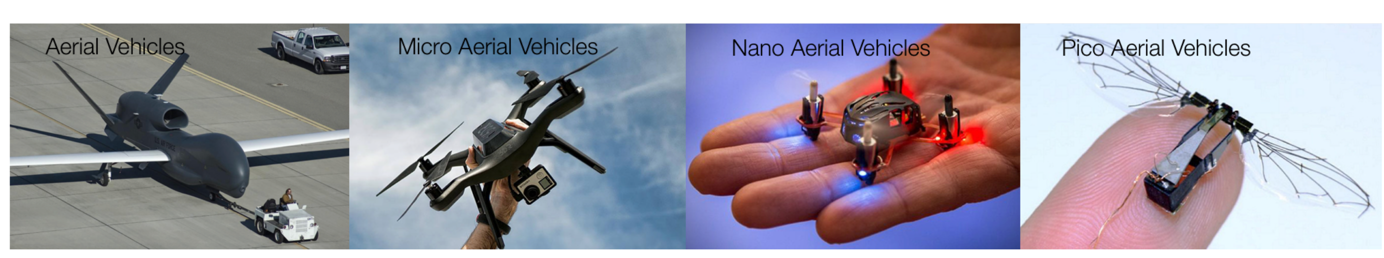
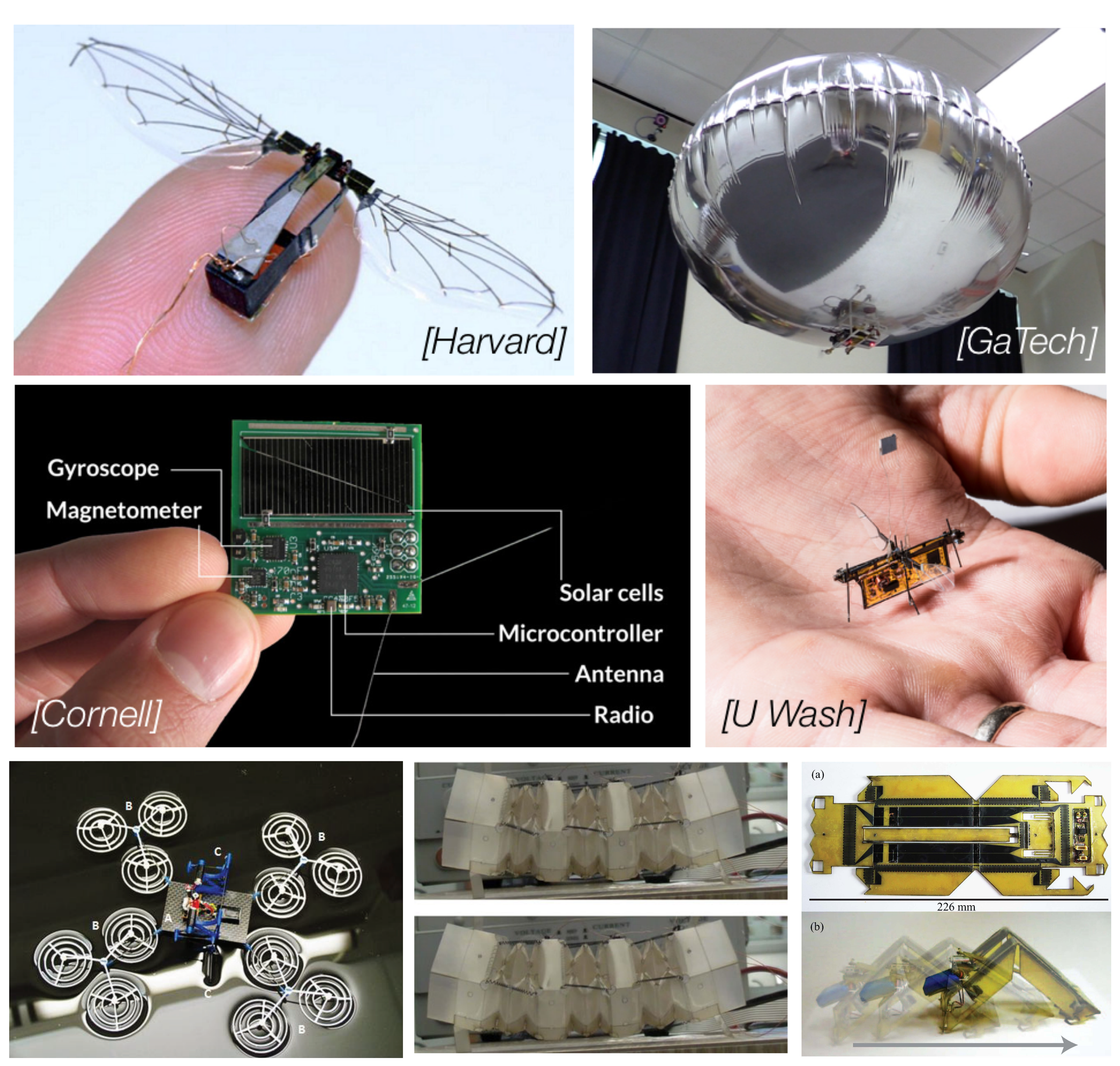
Research Opportunity

A broad range of next-generation CPS applications will be enabled by low-energy sensing and computing, in particular, by miniaturization. For instance, (i) insect-size drones with swarming capabilities in massive numbers, (ii) pill-size medical robots that can intelligently navigate the human digestion system, (iii) intelligent satellites on chip that can navigate far corners of the Solar system, (iv) low- energy glider drones and underwater vehicles that can operate continuously for months.

In the past decade, there has been tremendous advances in designing and building two of these elements, namely the sensors and actuators. However, powerful computers that modern artificial intelligence and autonomy depend on are still bulky, heavy and energy-hungry. The aforementioned applications require computers that are orders of magnitude smaller, lighter, and more energy-efficient. The current approach of developing algorithms and software that are designed for off-the-shelf general-purpose CPUs and GPUs, fails to deliver. A paradigm shift in computing is necessary towards enabling low-energy, miniature mobile robotic CPS that still provides provable guarantees on completeness, optimality, robustness and safety.
We will develop novel algorithms and computing hardware for low-energy mobile robotic Cyber-Physical Systems.



Design of miniature UAVs will be driven not by size/weight but by power.



Example low-energy mobile robotic CPS. Each vehicle consumes less than 1 Watt of electrical power for actuation.

Research Tasks

Research Task 1: Designing hardware and algorithms for visual-inertial state estimation

- Task 1.1: Image Buffer Compression with Provable Feature Detection/Tracking Performance Guarantees
- Task 1.2: Energy-efficient Feature Selection for Back-end with Provable Sub-optimality Guarantees

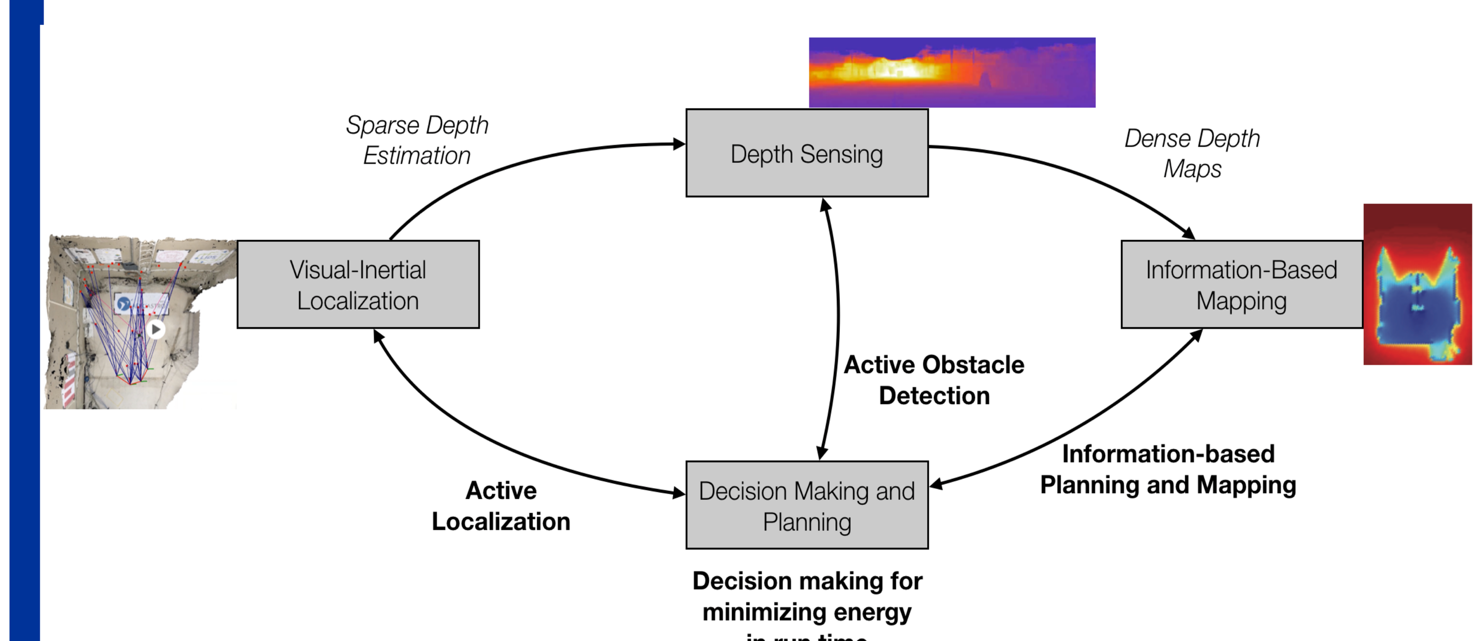
Research Task 2: Designing hardware and algorithms for mapping and information analysis

- Task 2.1: Creating Maps from Sparse Noisy Measurements
- Task 2.2: Image Compression for Mutual-information Maps for Exploration with Provable Guarantees on Information Loss

Research Task 3: Designing hardware and algorithms for decision making and planning

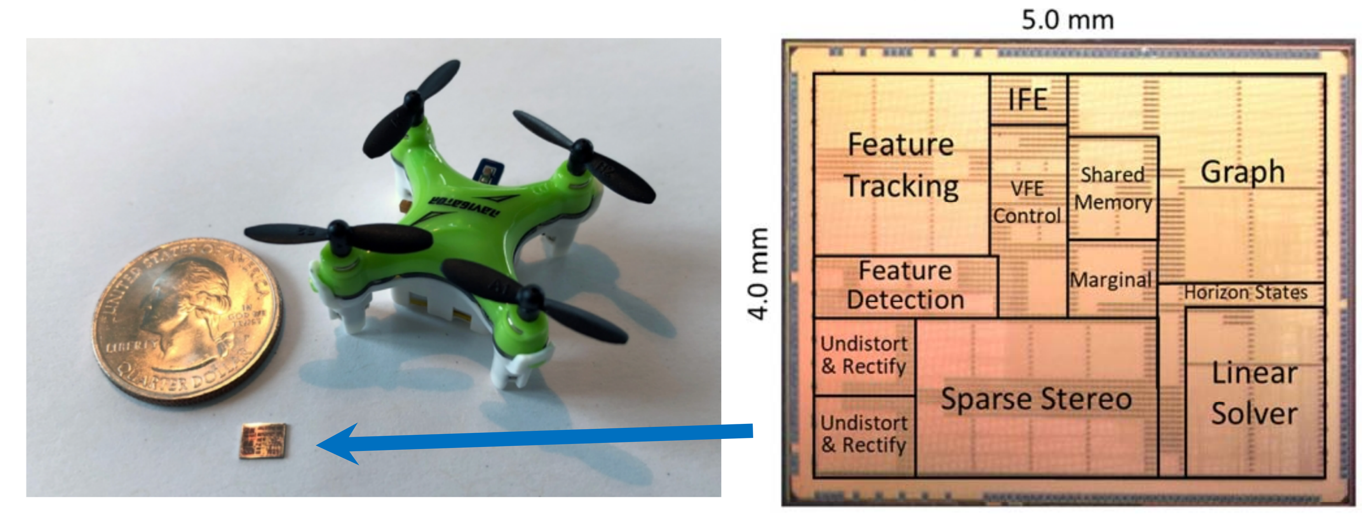
Research Task 4: Developing Principles for the Co-Design of Computing Hardware and Algorithms for Low-energy Robot Perception

Research Task 5: Systems Integration, ASIC Fabrication, and Experimental Evaluation



An example integrated system for low-energy mobile robotic CPS

Visual-Inertial Odometry on Chip

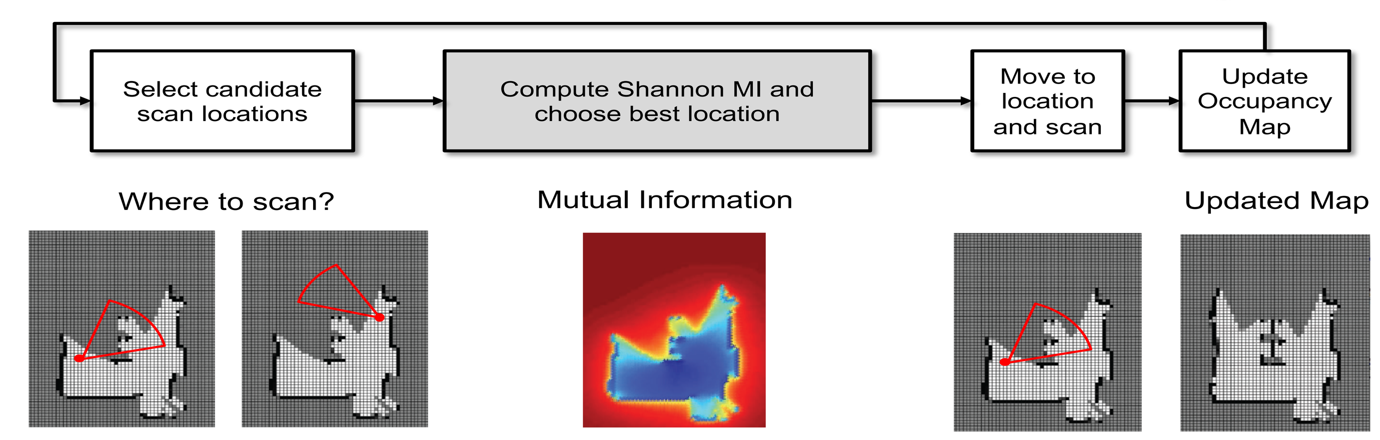


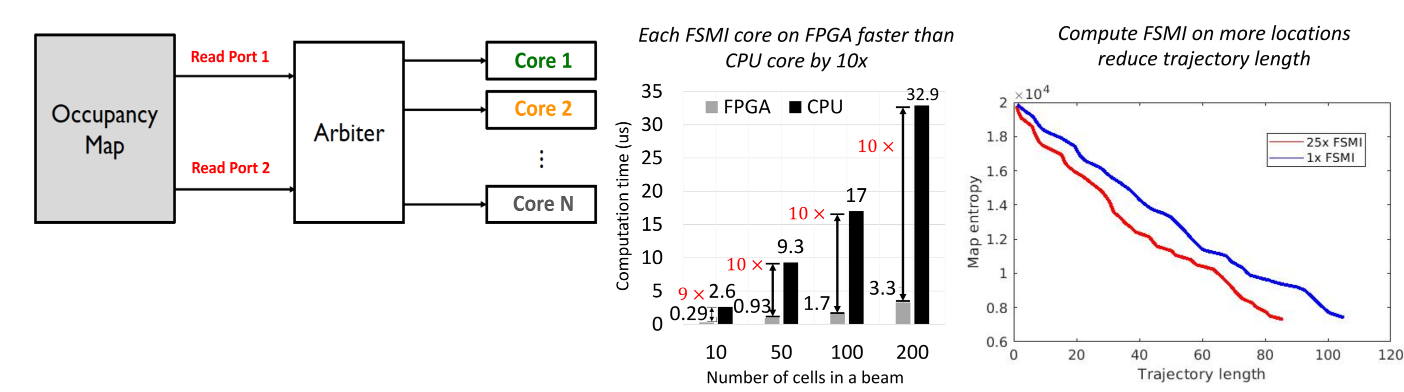
More info at http://navion.mit.edu

Technology	65nm CMOS	Supply	1 V
Chip area (mm²)	4.0 x 5.0	Resolution	752x480
Core area (mm²)	3.54 x 4.54	Camera rate	28 - 171 fps
Logic gates	2,043 kgates	Keyframe rate	16 - 90 fps
SRAM	854KB	Average Power	24 mW
VFE Frequency	62.5 MHz	GOPS	10.5 – 59.1
BE Frequency	83.3 MHz	GFLOPS	1 – 5.7

A. Suleiman, Z. Zhang, L. Carlone, S. Karaman, V. Sze, "Navion: A Fully Integrated Energy-Efficient Visual-Inertial Odometry Accelerator for Autonomous Navigation of Nano Drones," IEEE Symposium on VLSI Circuits, June 2018.
Z. Zhang*, A. Suleiman*, L. Carlone, V. Sze, S. Karaman, "Visual-Inertial Odometry on Chip: An Algorithm-and-Hardware Co-design Approach," Robotics: Science and Systems (RSS), July 2017.

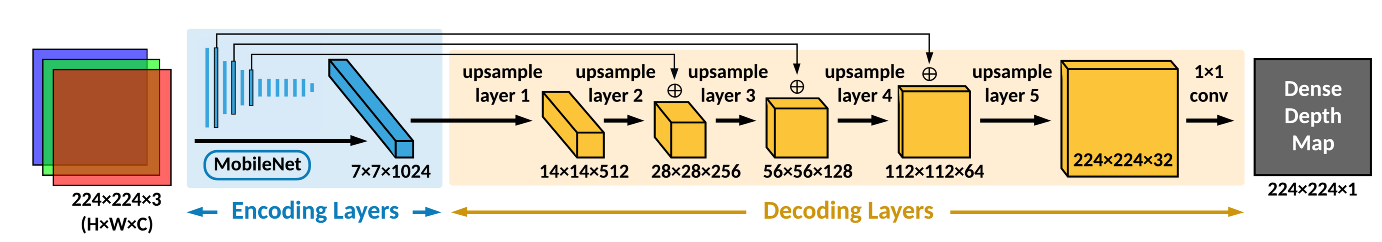
Information-theoretic Mapping

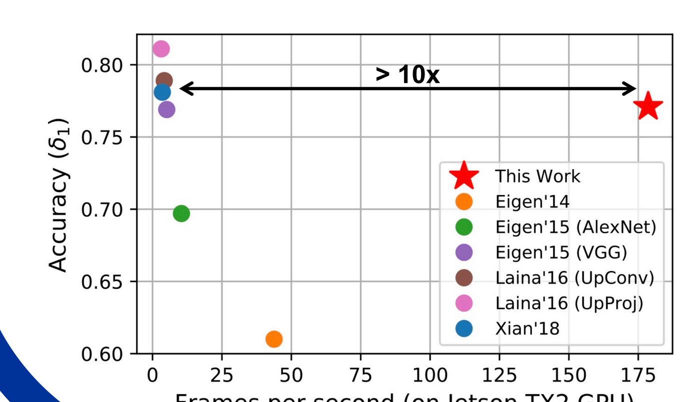




Z. Zhang, T. Henderson, V. Sze, S. Karaman, "FSMI: Fast computation of Shannon Mutual Information for information-theoretic mapping," IEEE International Conference on Robotics and Automation (ICRA), May 2019.
T. Henderson, V. Sze, S. Karaman, "An Efficient and Continuous Approach to Information-Theoretic Exploration," submitted to IEEE International Conference on Robotics and Automation (ICRA) 2020
S. Sudhakar, S. Karaman, V. Sze, "Balancing Actuation and Computing Energy in Motion Planning," submitted to IEEE International Conference on Robotics and Automation (ICRA) 2020

Depth Estimation





More info at http://fastdepth.mit.edu

D. Wofk*, F. Ma*, T.-J. Yang, S. Karaman, V. Sze, "FastDepth: Fast Monocular Depth Estimation on Embedded Systems," IEEE International Conference on Robotics and Automation (ICRA), May 2019.