Low-Energy computing for Autonomous Mobile Robotic CPS: A Hardware-and-Algorithms Co-design Approach

Sertac Karaman (MIT) & Vivienne Sze (MIT)

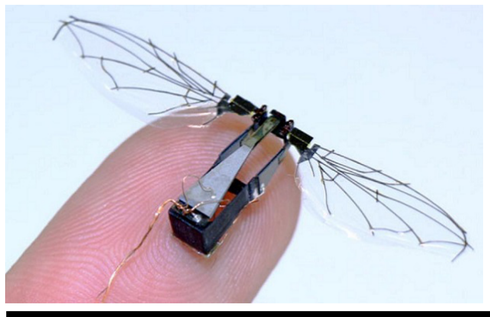
(#1837212, Sept 2018)

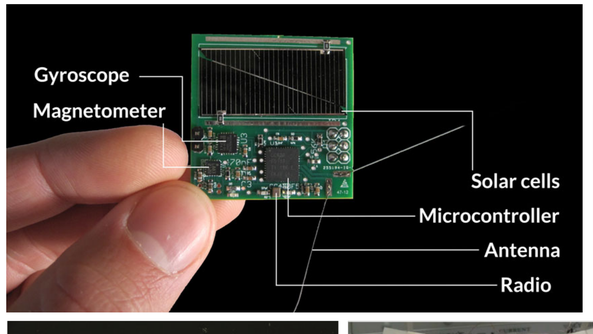
Challenge:

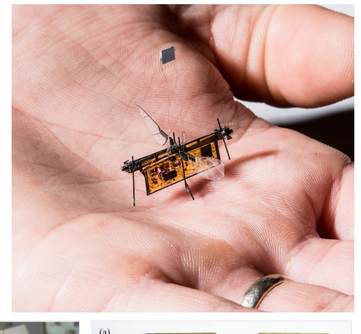
- Computing elements for low-energy robotics.
- Design computers from the ground-up to achieve energy requirements.

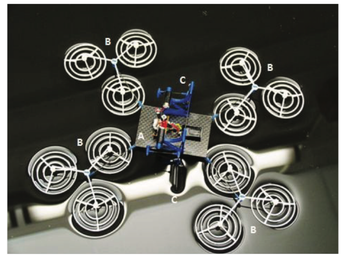
Solution:

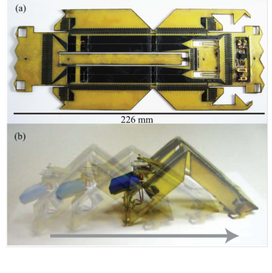
- *Co-design* of algorithms and computing hardware.
- Focus on data flow rather than, e.g., number of operations.











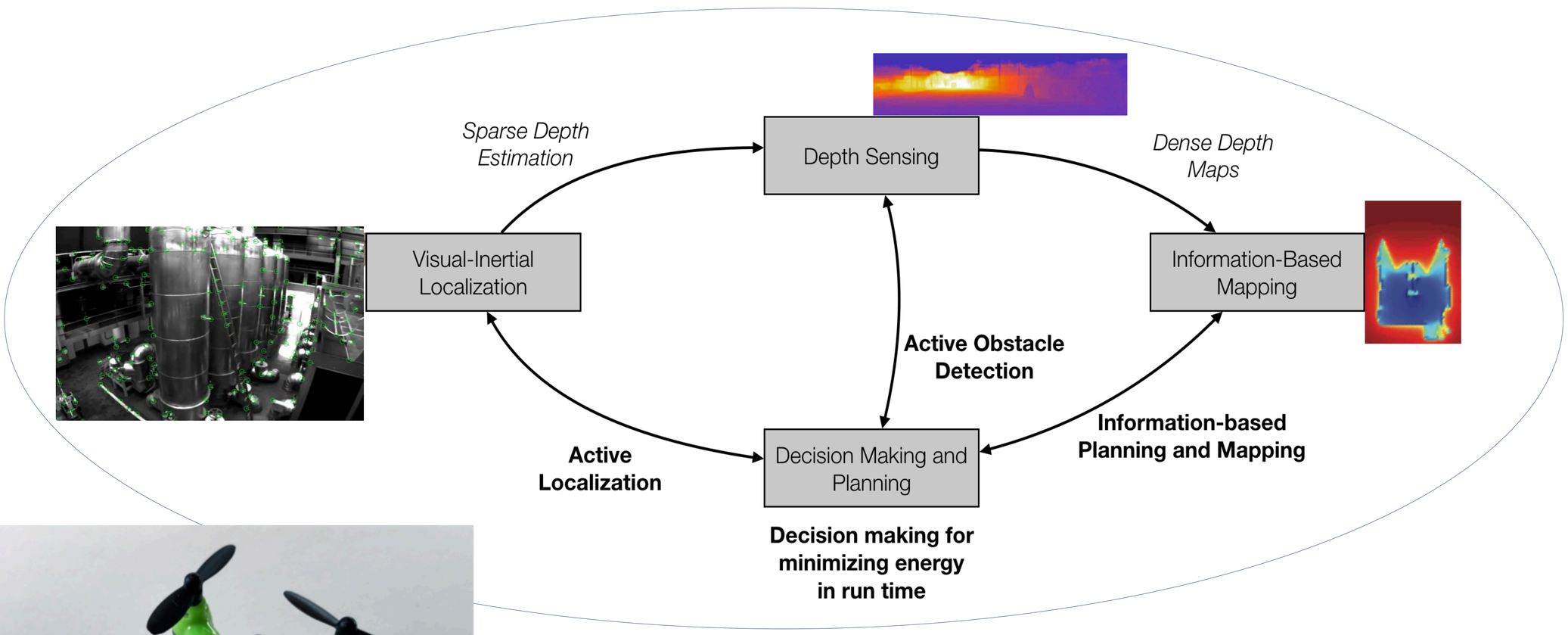
Award no: 1837212,
Start date: Sept 2018
Pis: Sertac Karaman & Vivienne Sze

Scientific Impact:

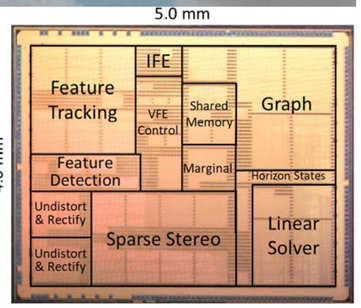
- Revisit robotics algorithms from the perspective of computing hardware.
- Recent results demonstrate three orders of energy savings in visual navigation.

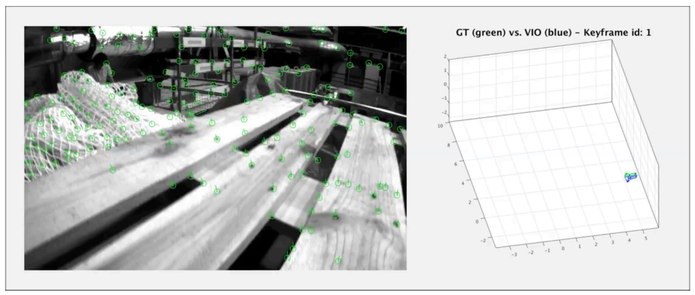
Broader Impact:

- Enables miniature and/or high-endurance vehicles for
  - Environmental monitoring
  - Consumer devices
- Foster community at the intersection of robotics, integrated circuits and computer architecture.



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





- **First Chip on Complete Visual-Inertial Odometry**
- **Enabled by:**
  - –On-chip image buffer compression,
  - –Novel floating arithmetic,
  - –Sparse matrix operations, …

PUBLICATIONS

[1] 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.
[2] 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.
[3] 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.
[4] 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
[5] 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.
[6] 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.