CAREER: Multi-Agent Decision Making and Optimization using Communication as a Sensor

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https://github.com/Harvard-REACT/WSR-Toolbox

Problem

- Obtain and mathematically characterize useful information based on the physical properties of local communication signals to inform CPS multi-agent algorithms.
- Develop a system to enable CPS agents to obtain this information via edge computing.

Scientific Impact

- Off-the-shelf robots are equipped with a new realtime on-board sensing capability to estimate Angle-of-Arrival (AOA) to other robots.
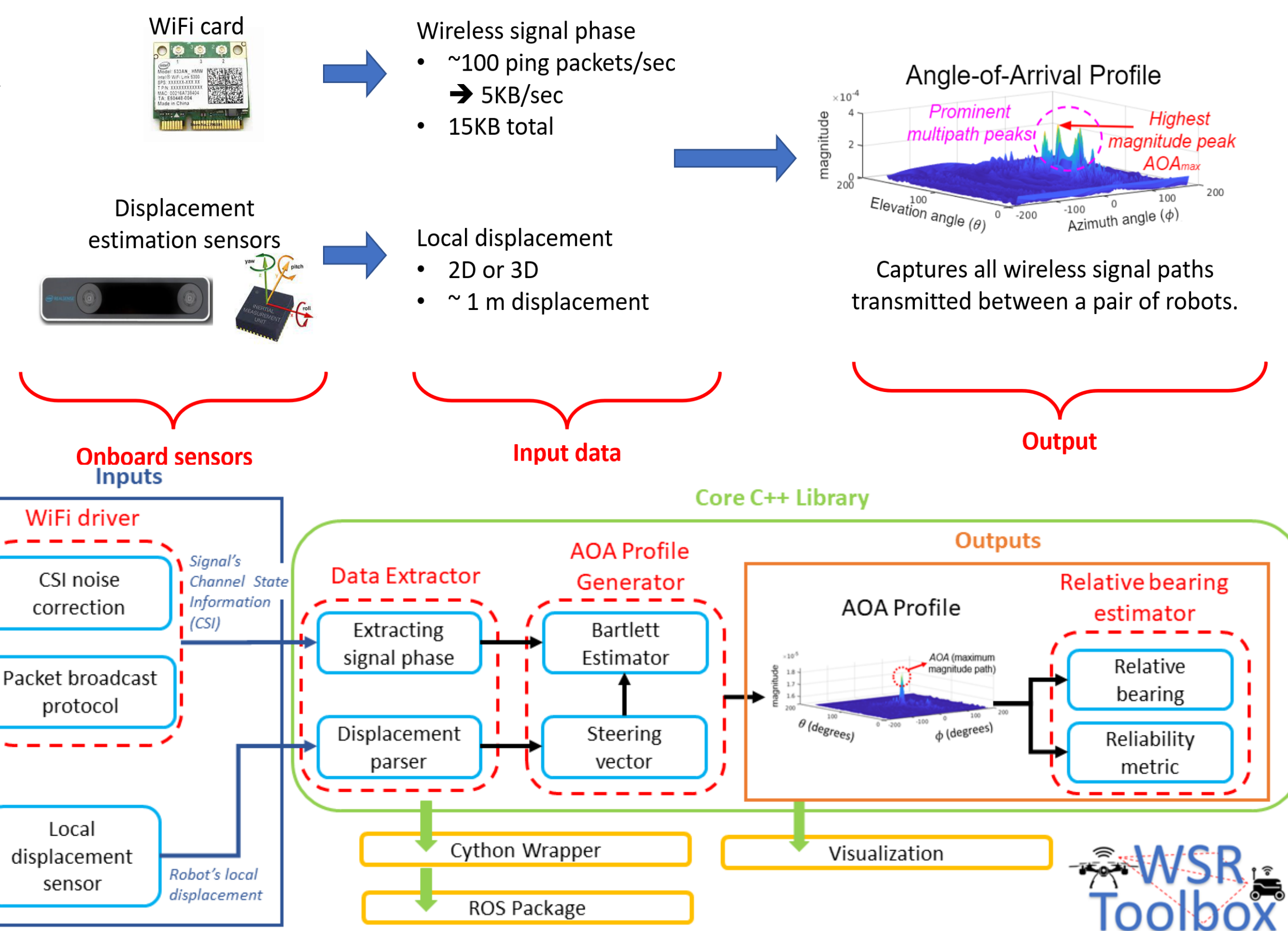- Mobile robots can optimize the accuracy of AOA by controlling their mobility in 2D/3D space.

Technical Approach

- A mobile robot such as UAV can use its free motion in 3D to construct a virtual antenna array using a method akin to Synthetic Aperture Radar (SAR).
- Using its local displacement during the motion and received communication signals, the UAV can estimate relative direction of neighboring robots.
- A lower bound on the variance of AOA estimate due to geometry of robot's motion and analysis of the impact of displacement estimation error on the AOA profile is provided.

Arbitrary 3D displacement of UAV

AOA Profile (side view)

AOA Profile (top view)
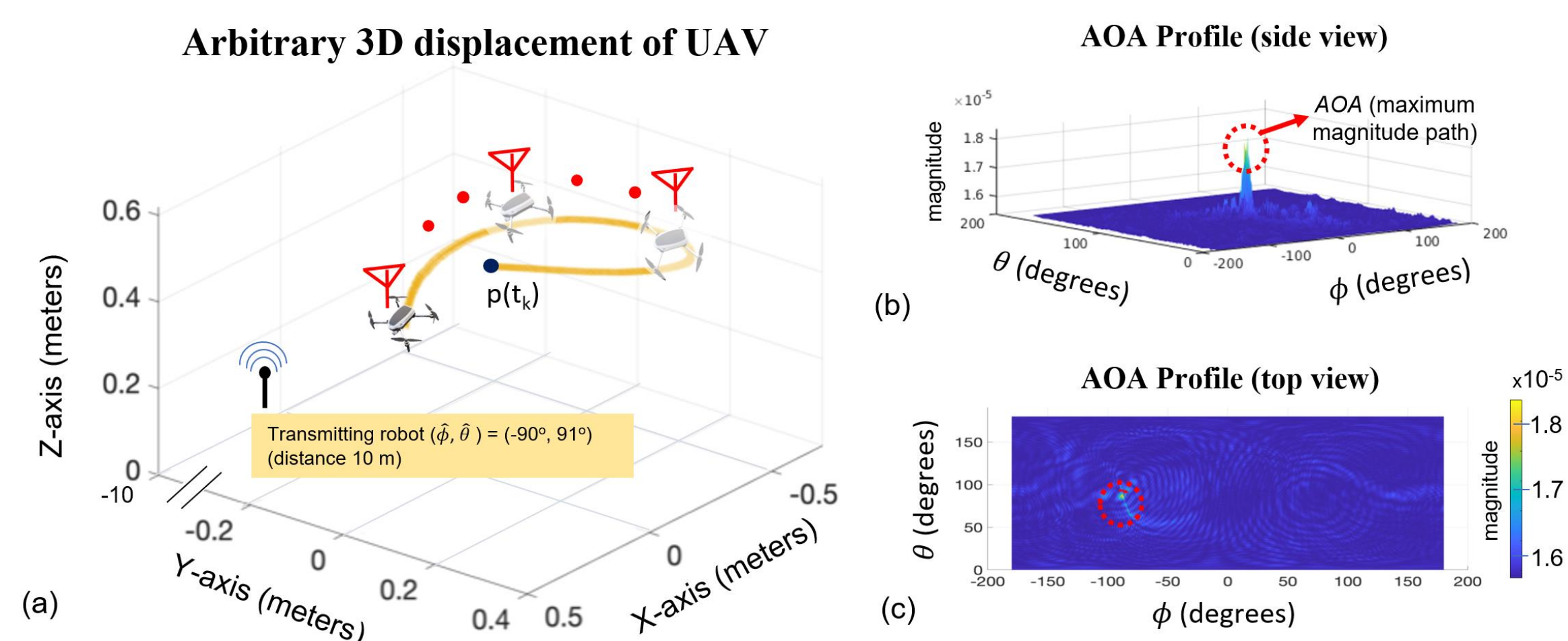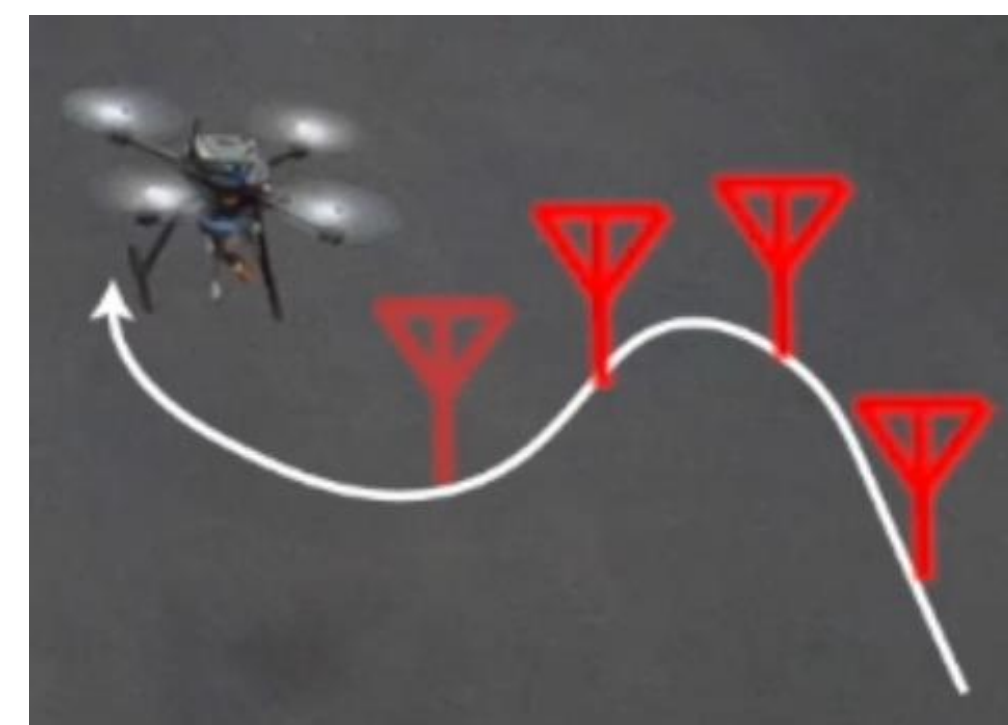
New Contributions

- Opensource *WSR Toolbox* developed in C++ and compatible with Python and ROS.
- Uses off-the-shelf hardware components and can be deployed on robot's onboard computer.

WiFi card — Wireless signal phase
- ~100 ping packets/sec → 5KB/sec
- 15KB total

Displacement estimation sensors — Local displacement
- 2D or 3D
- ~ 1 m displacement

Angle-of-Arrival Profile — Captures all wireless signal paths transmitted between a pair of robots.

Broader Impact

The WSR Toolbox is open-sourced to make the Angle-of-Arrival profile accessible to the wider robotics community for the first time. It can be leveraged for

- Coordinated algorithms such as multi-robot exploration.
- Search and rescue tasks where robots can perform as part of a hybrid team (human/autonomous teams).
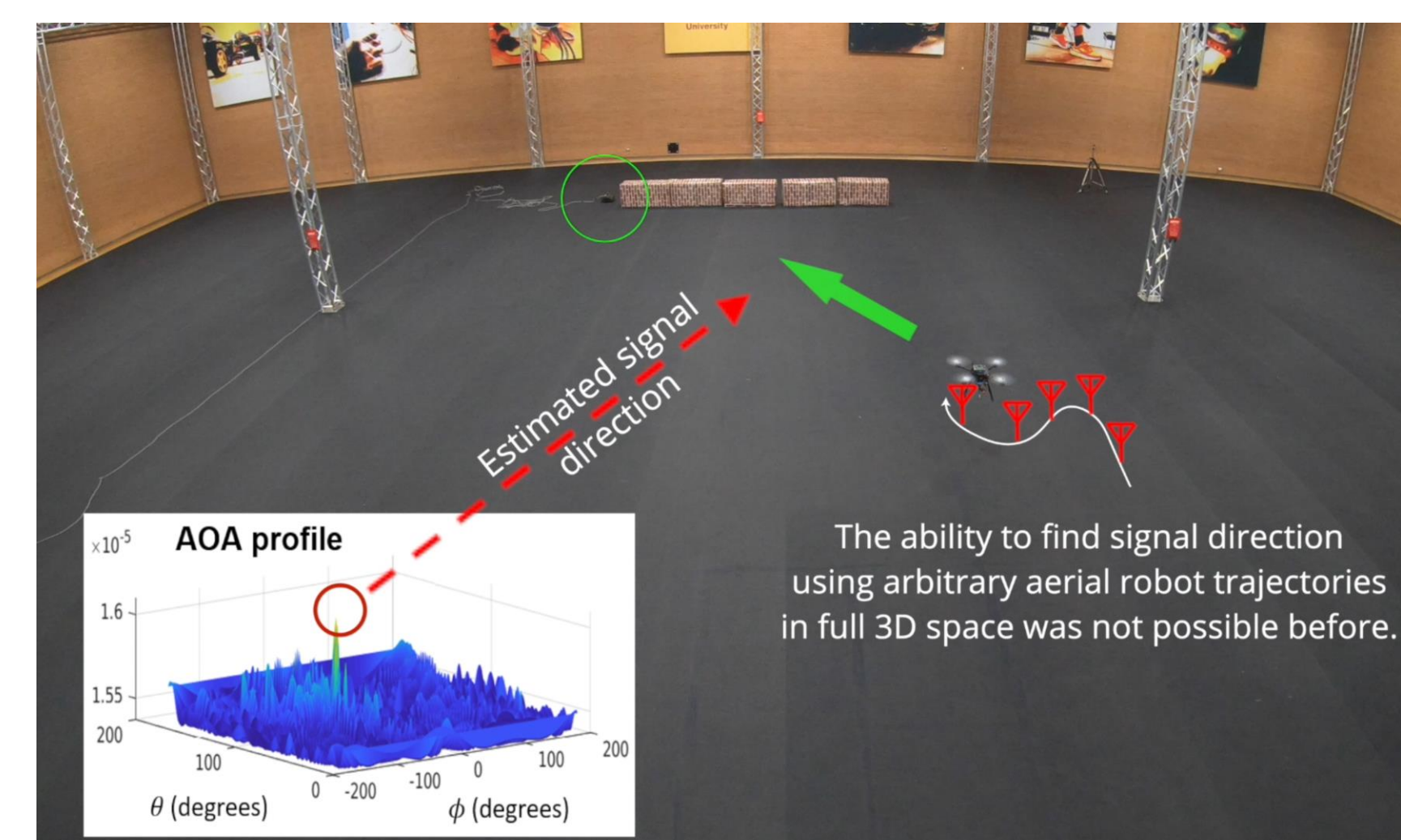
Education and Outreach

- WSR toolbox introduced as mini-hack workshop for Harvard graduate course "CS286 : Multi-Robot Systems – Control, Communication, and Security."
- Students showcased the use the WSR toolbox as part of their final project themed "Search and-rescue judged by Jesse Robinson, Arizona's statewide search and rescue coordinator for the Department of Emergency and Military Affair (DEMA).

Applications

Dynamic rendezvous between UAV and ground robot

AOA profile — The ability to find signal direction using arbitrary aerial robot trajectories in full 3D space was not possible before.

Robot localization in non-line-of-sight

Signal receiving robot
Signal Transmitting robot

[1] Ninad Jadhav*, Weiying Wang*, Diana Zhang, Oussama Khatib, Swarun Kumar and Stephanie Gil. "A wireless signal-based sensing framework for robotics." *The International Journal of Robotics Research* 41 (IJRR - 2022): 955 - 992.

[2] Ninad Jadhav, Weiying Wang, Diana Zhang, Swarun Kumar and Stephanie Gil. "Toolbox Release: A WiFi-Based Relative Bearing Sensor for Robotics." *International Conference on Intelligent Robots and Systems* (IROS - 2022).