the advent of low-cost, low-power millimeter (mm)-wave RF transceivers [3], which enables the exploitation of RF sensors almost anywhere.

CAREER: InteractiveRF: Fully-Adaptive, Physics-Aware RF-Enabled Cyber Physical Human Systems (CPHS)

PI: Dr. Sevgi Zubeyde Gurbuz, The University of Alabama, Tuscaloosa, AL

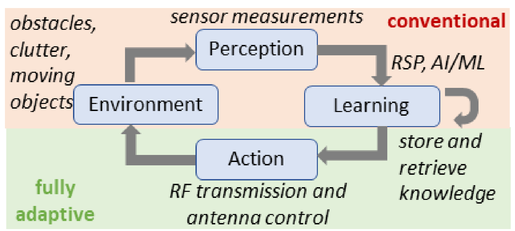
Project Website: *https://ci4r.ua.edu/career-interactive-rf.html*

How can we design autonomous systems where human-system collaboration is optimized through improved understanding of human behavior?

The advent of low cost, low power, and small RF transceiver chips is driving a revolution in millimeter wave (mm-wave) sensing, where now RF sensors can be placed anywhere – in the home, in your car, in hand-held devices, or even in clothing.

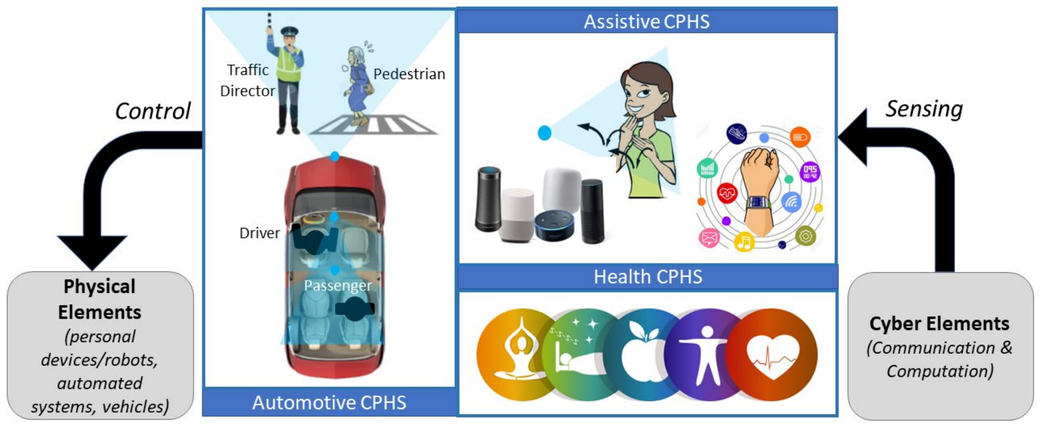
Vision*: Advance CPHS by transforming the way RF sensors are designed and utilized in CPHS :*

1. *Human-centric Fully-Adaptive RF Sensing:* Add a feedback loop controlling the RF transmission waveform and beampattern to optimize RF sensing in response to dynamic human behavior and environment.



Fully-adaptive RF sensing: RF transceiver can be controlled in a stand-alone fashion or guided by sensors of other modalities.

2. *Physics-Aware AI/ML:* Take advantage of what we already know about the physics of RF backscatter and biomechanics of the human body to bridge the data gap and empower deep neural networks (DNNs) to better learn and recognize human motion.
3. *Componentwise Kinematic Parsing of RF Data Streams:* Break down human RF signal into kinematically meaningful segments and components to enable understanding of most relevant movements in a continuous fashion

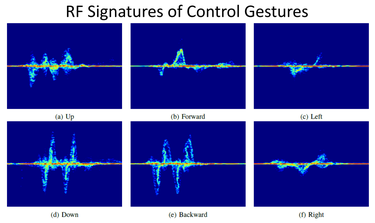


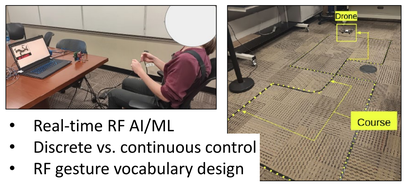
Scientific Impact:

- Contributes to data analytics, machine learning, real-time human-in-the-loop control, autonomy and Internet-of-Things (IoT) that utilize RF sensors
- Advances methods for dynamic interactions of humans and autonomous systems by enabling improved human behavior understanding in real-world environments
- Re-imagines RF sensing by adding an adaptive feedback loop into the RF sensor itself, which enables optimization of performance under dynamic conditions
- Establishes a collaborative framework for multi-modal collaborative sensing via adaptive control of RF TX

RF-enabled Gesture-Controlled Drone Racing

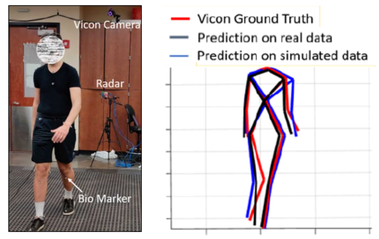
RF Signatures of Control Gestures





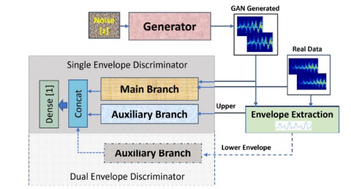
- Real-time RF AI/ML
- Discrete vs. continuous control
- RF gesture vocabulary design

RF-Skeleton and Gait Parameter Estimation

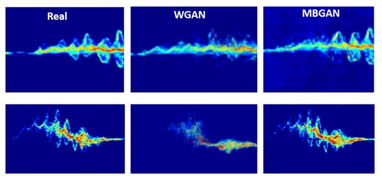


- Design of RF skeleton estimation from RF data cube (range, velocity, azimuth, elevation vs. time)
- Validation of estimation accuracy against gold standard optical tracking
- Incorporation of temporal correlations to estimation process
- Estimation of gait parameters for fall risk assessment

Physics-Aware GANs for RF Data Synthesis



Dual-Envelop Discriminator with physics-based loss function reduces kinematic errors in synthetic samples:



ChessSIGN: Interactive ASL-Controlled Chess Game via RF

(a) Highlighted possible moves with assigned (b) UNDO button for correcting wrong predictions. (c) Feedback GUI for correcting misclassifications.

Impact on Education:

- Multi-Disciplinary Research Internships [1 GRA]
- Research Experiences for Undergraduates [1 URM]
- STEM Activity Development
- IEEE Radar Challenge Team

Impact on Society:

- Advancement of assistive technologies for Deaf/Hard-of-Hearing community
- Improved remote health monitoring, aging-in-place
- Improved quality of life via HCI

Publications:

- "Interactive Learning of Natural Sign Language with Radar," IET Radar Sonar Navigation, 2024
- "CV-SincNet: Learning Complex Sinc Filters From Raw Radar Data for Computationally Efficient Human Motion Recognition," IEEE Trans. Radar Systems, vol. 1, Aug. 2023
- "Gamification of RF Data Acquisition for Classification of Natural Human Gestures," IEEE Radar Conference, Denver, CO, May 2024
- "Radar-Based Joint Human Activity and Agility Recognition via Multi-Input Multi-Task Learning," IEEE Radar Conference, Denver, CO, May 2024.
- "Radar-Based Human Skeleton Estimation with CNN-LSTM Network Trained with Limited Data," IEEE Biomedical and Health Informatics Conference, Pittsburgh, PA, Oct. 15-18, 2023

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