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RF-driven Human Sensing Beyond Line-of-Sight

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1 UGRC Problem Statement

In this project proposal, we intend to leverage the versatility of Radio Frequency (RF) waves to perform ambient sensing in a region surrounding a wireless channel. In particular, our goal is to perform device-free and passive human surveillance along with accurate detection of concealed, on-body metallic artifacts such as weapons. Such artifacts are otherwise difficult or infeasible to be detected using visual sensing modalities that typically works in Line-of-Sight (LoS) scenarios. 'Device-free' here refers to the fact that the target entities (e.g., human) need not carry any devices or sensors attached to their body. To this end, we propose to design and implement an end-to-end system that performs such sensing in supplement to exisitng visual sensing modalities to enhance its capabilities beyond LoS. Specifically, we intend to use mmWave radars [1] [2] [3] that provides a higher imaging resolution along with moderate LoS penetration.

2 Relevant Background

In the following we introduce some key background terms that are relevant to the project.

- **RF waves** are electromagnetic waves with wavelength more than around 1mm. They have a wide variety of applications like communications, sensing and astronomy. This is mainly due to their long wavelength that allows them to penetrate media that other parts of the EM spectrum cannot.

- **Ambient sensing** using RF involves detecting and analyzing the RF signals present in the environment to infer contextual information about the surroundings. This is a passive technique and is done without requiring direct interaction with objects or individuals.

  RF signals emitted by wireless devices, like Wi-Fi routers, cellular towers, and Bluetooth devices, are used to probe the environment. These signals interact with the objects in the environment, via reflections, diffraction, and absorption. By analyzing the changes in the characteristics of these signals, such as amplitude and phase, it's possible to extract information about the environment.

- **Signal Processing.** In human environments, the abundance of radio noise means that the information gathered during sensing often includes numerous signals beyond the one of interest. Hence, employing signal processing techniques becomes essential to clean and filter the data, boost the signal-to-noise ratio (SNR), and derive valuable insights. Recent advances in deep learning techniques (for instance, *autoencoders*) have led to sophisticated noise reduction methods that work in near realtime. They also leverage from specific patterns of noise that can be pre-trained based on specific wireless contexts.

- **Frequency Modulated Continuous Wave (FMCW) Radar** is a special type of radar sensing method that uses *chirps* as a sensing signal – the frequency of the signal increases with time (typically, linearly). It allows us to measure target range and velocity simultaneously via estimation of doppler shifts, while also providing high accuracy.

3 Outline of Work / Timeline

- **Exploring Wireless Modalities**
  - Exploration of wireless modalities: WiFi, Ultra-Wideband, and Millimeter waves.
  - Investigate the advantages and limitations of each modality in the context of RF-driven human sensing and concealed object detection by analyzing factors such as range, penetration capabilities, signal resolution, and interference susceptibility.

- **Setting Up Experimental Test-Bed and Data Collection**
  - Configure wireless signal transmitter and receiver setups for data collection, in a controlled environment for conducting experiments, ensuring accuracy of results.

- **Data Filtering**
  - Use machine learning techniques such as PCA for feature extraction and dimensionality reduction and denoising techniques for data preprocessing.
  - Fine-tune parameters to optimize data filtering performance, aiming to enhance signal clarity and reduce noise interference.

- **Signal Analysis with Metallic and Non-Metallic Objects**
  - Conduct controlled experiments using simple metallic and non-metallic objects and collect RF signal data.

  - Mapping techniques to correlate denoised data with trajectory geometry and reflector properties, to understand the data.

- **Model Training for Inference**
  - Develop and train machine learning models such as Multi Layer Perceptron or CNN on collected data to infer human activities and detect concealed metal objects, such as weapons.

- **Integration with Visual Sensing (If Time Allows)**
  - Integrating wireless sensing with visual sensing technologies: overlay RF-detected objects onto camera feeds in real-time.

References

[1] Anjun Chen, Xiangyu Wang, Shaohao Zhu, Yanxu Li, Jiming Chen, and Qi Ye. mmbody benchmark: 3d body reconstruction dataset and analysis for millimeter wave radar, 2023.

[2] Kun Qian, Zhaoyuan He, and Xinyu Zhang. 3d point cloud generation with millimeter-wave radar. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 4:1–23, 12 2020.

[3] Argha Sen, Anirban Das, Swadhin Pradhan, and Sandip Chakraborty. Continuous Multi-user Activity Tracking via Room-Scale mmWave Sensing. *arXiv e-prints*, page arXiv:2309.11957, September 2023.