Towards Robust Pedestrian Detection with Roadside Millimeter-Wave Infrastructure

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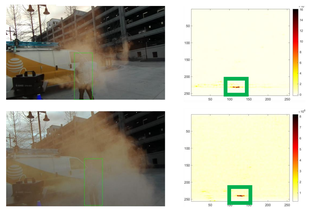
Research Motivation

Vehicle-pedestrian collisions are the leading cause of roadside fatalities

- Despite strict traffic laws, fatal pedestrian collisions occur daily and demand pedestrian monitoring at intersections.
- Cameras and LiDARs could detect pedestrians and alert vehicles nearby but fail during heavy rain and foggy condition.
- 5G-and-beyond networks (picocells) offer high data rates and have millimeter-wave (mmWave) as their core technology.
- Due to high operating frequency and small coverage, picocells are expected to be deployed at traffic intersections.

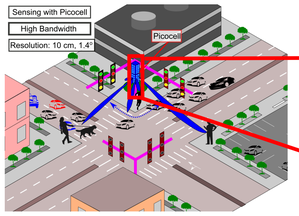
LiDAR



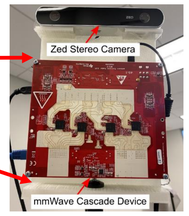
Camera mmWave device

Millimeter-wave device works in all weather conditions

- MmWave signals can penetrate through fog and rain, get reflected from surrounding objects, and works in all weather conditions.
- Our objective is to monitor pedestrians and vehicles in all weather conditions using a picocell installed at a traffic intersection.



mmWave device at intersection



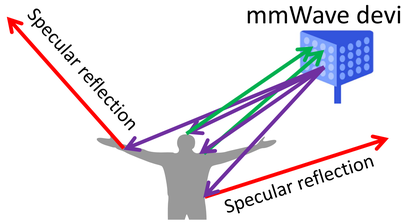
Our setup

Data collection scenario

Challenges of Millimeter-Wave

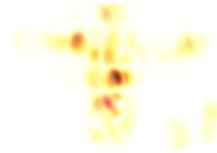
Specularity of millimeter-wave signals and weak reflectivity of pedestrians

- The pedestrian body surface acts as a mirror, reflects most mmWave signals away from the receiver, and generates shape with most regions missing.
- Specularity doesn't affect cameras with Line-of-Sight (LoS) vision because light scatters more than mmWave, but cameras fail under harsh weather conditions.



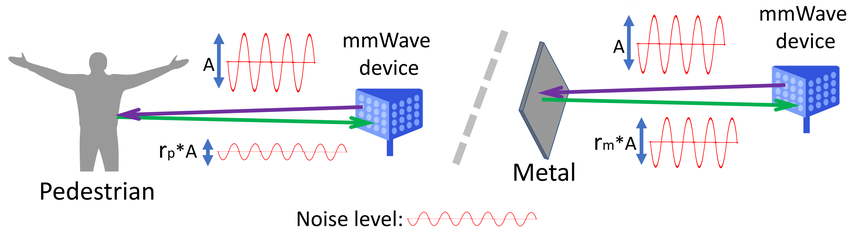
Pedestrian

Camera in LoS



mmWave device

- The weak reflectivity of the pedestrian causes the amplitude of the received signal to be significantly lower than the amplitude of the transmitted signal.

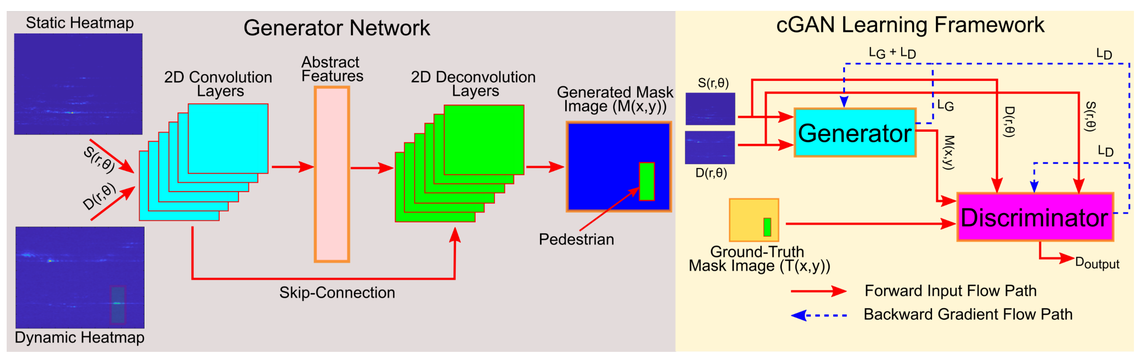


(r_p, r_m) = mmWave signal reflectivity of pedestrian and metal

Proposed Approach

Conditional Generative Adversarial Networks (cGAN) recover missing regions

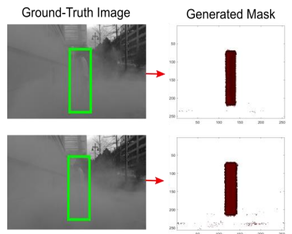
- cGAN can produce unseen images in a given domain with random noise and limited image descriptions (condition), providing intuition to recover missing regions.
- In our approach, cGAN generates pedestrian mask images from low-resolution mmWave heatmaps after learning from thousands of data samples.
- Due to the lack of open-source data, we collect data with a custom mmWave device and stereo camera setup at a traffic intersection to train and evaluate our model.

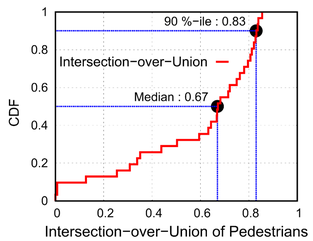


Preliminary Results and Future Works

Accurate prediction of 2D bounding boxes for pedestrians

- Our system accurately predicts 2D bounding boxes of single and multiple pedestrians at a traffic intersection with a mmWave device.
- We generate 2D bounding boxes with a median Intersection-over-Union (IoU) of 0.67 on 3000 test samples, indicating high accuracy in pedestrian detection.





Future Works

- We plan to collect more data samples at different intersections to improve results and extend our system to car, bus, and truck detection.
- We will upgrade our design to share a single mmWave device for networking and sensing without compromising networking.

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