WIP: Augmenting Vehicle Safety With Passive BLE

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What is Dooring?

- Vehicle passenger opens door into path of vulnerable road user (VRU)
  - E.g., bicycles, e-scooters, runners
- Pervasive accident & high injury rate:
  - ~1 per day in Chicago
  - Over 80% of accidents left biker seriously injured in San Francisco
  - Most common cycling accident type in Vancouver

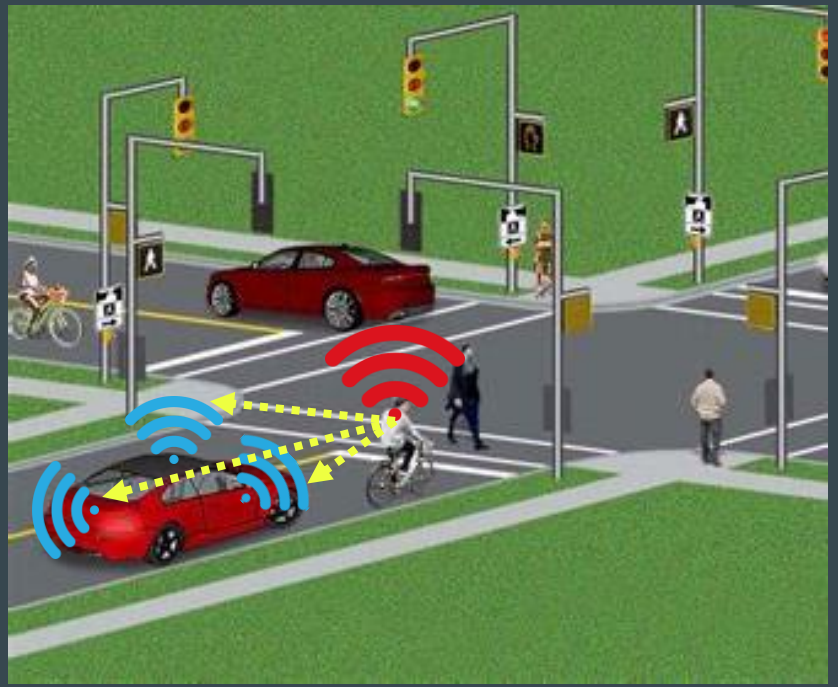
https://ftw.usatoday.com/2014/09/bike-lane-new-york-crash

Shortcomings of SOTA Dooring Prevention Solutions

- Prohibitively expensive
  - LiDAR
- Line-of-sight issue
  - Camera, radar
- VRU opt-in required
  - Vehicle-to-pedestrian
  - Bluetooth Low-Energy (BLE) pairing
- Impractical
  - Vehicle modification

Providing Vehicles With Low-Cost Dooring Prevention

- Pedestrian mobile devices passively transmit Bluetooth Low-Energy (BLE) advertising (AD) packets
- Vehicles are equipped with multiple BLE receivers at various locations
- `S-Door`:
  - Passively observe AD packets from each receiver use RSSI as a proxy for distance



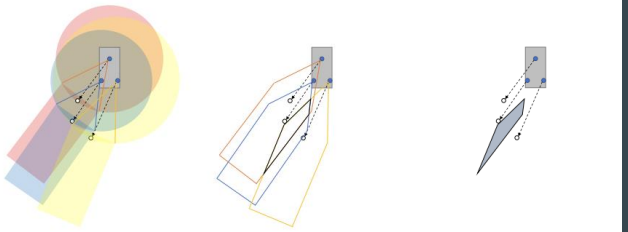
https://www.ontario.ca/fr/page/conduite-aux-passages-pour-pietons-et-aux-passages-pour-eleves

Localizing VRU Using (Inaccurate) RSSI and Angle-of-Arrival

- Triangulation
  - Requires precise direction
- Trilateration
  - Requires precise distance
- Outside bounds of receivers
  - Multiple solutions
- Triangulation-Trilateration (TRI^2)

Algorithm 1: TRI^2: Triangulation-Trilateration

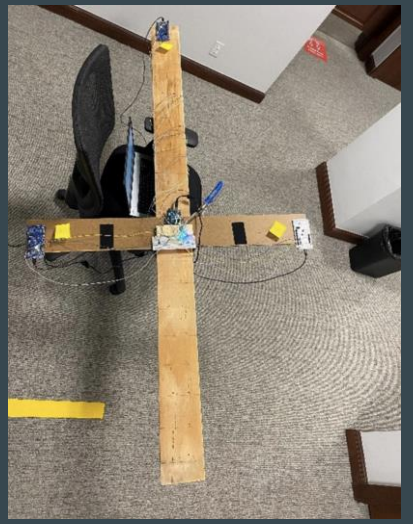
Data: A list $\boldsymbol{X}$, where $X_i = (RSSI_i, d_i, \theta_i, p_i)$.
Result: p, the predicted position of the VRU.
$\boldsymbol{S} \leftarrow \emptyset$;
/* Step 1: Create circle sectors and rectangles to union them and generate pentagons. */
foreach $X_i \in \boldsymbol{X}$ **do**
  $C_i \leftarrow CircSector(d_i, \theta_i - \delta, \theta + \delta, p_i)$;
  $R_i \leftarrow Rect(2(l + d_i), d_i \frac{\sin(2\delta)}{\sin(\frac{1}{2}(180 - 2\delta))}, p_i)$;
  $\boldsymbol{S}.append(UnionShapes(C_i, R_i))$;
end
/* Step 2: Intersect generated pentagons. */
$I \leftarrow IntersectShapes(\boldsymbol{S})$;
/* Step 3: Find weighted center of the polygon. */
$p \leftarrow WeightedCenterShape(I)$;



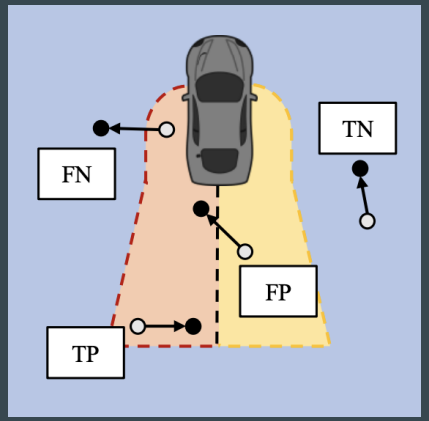
(a) Step 1. (b) Step 2. (c) Step 3.

Results

- 10 trials each for VRU walking, running, and biking
- VRU detected with True-Positive Rate of 100%
- But… Still many false-positives (FPs)
  - A detected VRU is misidentified as being nearby and behind the vehicle



Prototype of `S-Door`



Concluding With Remaining Work

- Thorough evaluation of angle-of-arrival transmission capabilities from smartphones
- Implement `S-Door` in real vehicle
- Test in more diverse set of environments
- Assess privacy implications of using AD packets to locate VRUs (via user studies)

Resources:

- Websites
  - https://www.linkedin.com/in/noah-curran/
  - https://rtcl.eecs.umich.edu/rtclweb/
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