Work Zone Safety

AlertBLE: Alert Work Zone Hazards Using AI Enabled BLE

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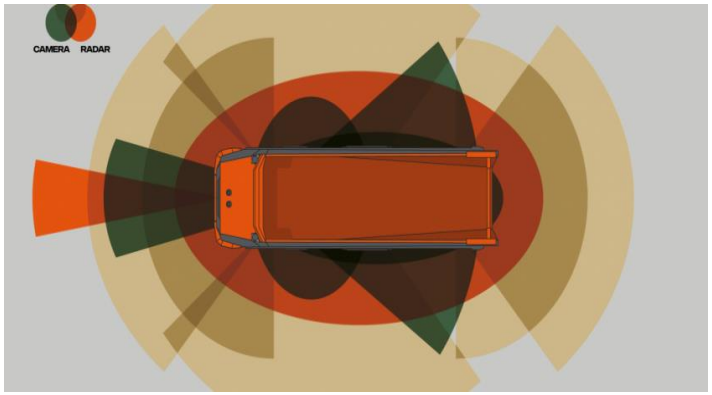
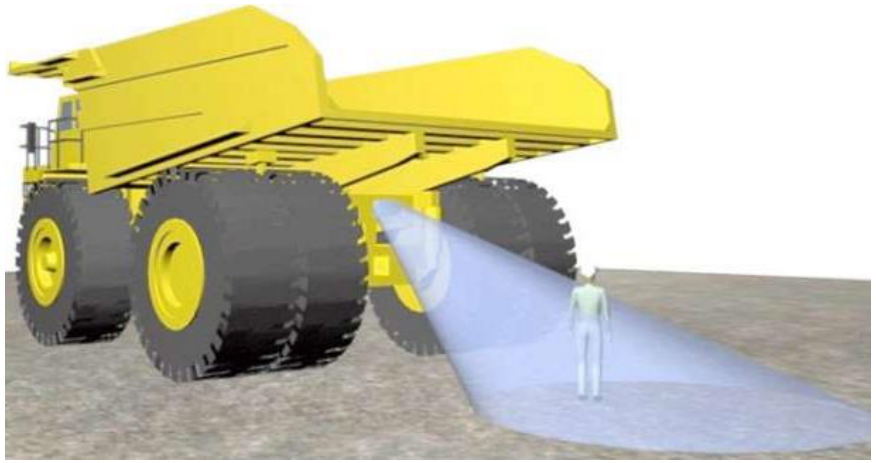
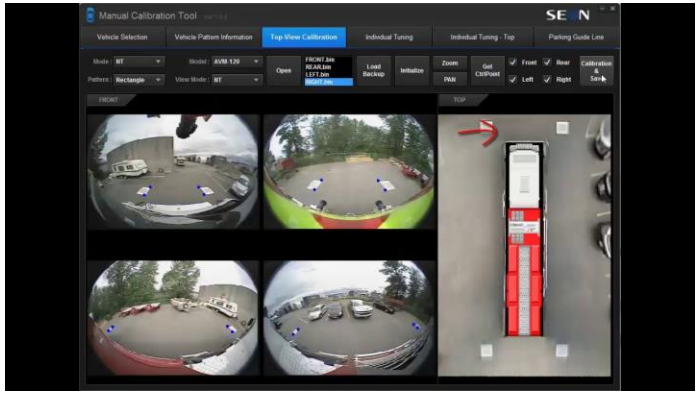
Existing Proximity Detection and Warning Systems

- Proximity monitoring technologies (video cameras and additional rearview mirrors)
- Smart collision avoidance or proximity detection and warning systems (GPS, uwb, radar and sonar devices or tag-based systems) https://www.designworldonline.com/ultra-wideband-factors-to-consider-before-you-get-started/







Existing Proximity Detection and Warning Systems

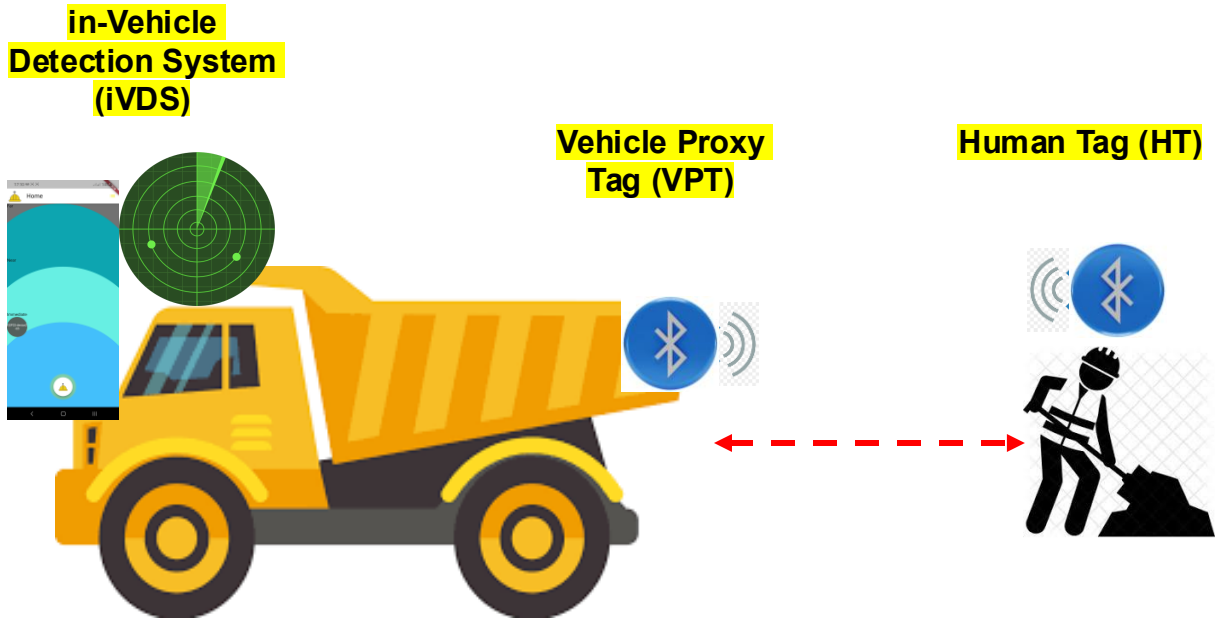
- **Video camera/ radar-based approach**
  - One-way (for the operator) monitoring system.
  - The workers on foot cannot sense upcoming hazards with this video system.
  - The operator needs to be vigilant about the environment by monitoring the video screen.
  - Cannot detect any objects out of the line of sight and in a blind spot.
- **Magnetic tag** approach is single direction and cannot cope with the blind spot issues.
- **Back-up sound alerts are u**nreliable due to various noisy distractions.
  - May not be able to hear the sound alert.
- **Control personnel and visual warning signs**
  - Require workers active attention.
  - Capacity limitation: lack the adaptability to the mobile hazards.
  - Not scalable.
- **Absolute location** (i.e., GPS) does not work indoor.
- **Ultra-wideband (UWB) technology** is most accurate location approach, but radio waves are absorbed by electrically conductive metals and water (i.e., human). So, UWB will penetrate drywall, but not steel, or concrete.
  - difficult to implement in a warehouse filled with dense rack and heavy trucks.
  - requires more power to operate.

Project Overview

- Motivation
  - Preventing work/construction zone crashes and incidents.
- Objective
  - Conduct a critical review of existing commercial alert systems.
  - Develop an affordable, easy-to-use, adaptable, prompt, accurate, and reliable hazard detection and alert system that can overcome the limitations of existing commercial alert systems.
- Methodology
  - Review of existing literature and practices.
  - Develop a system that connects vehicles and crews using advance technologies.
  - Field evaluations of the hazard detection and alert system for the implementation and a system maintenance plan.

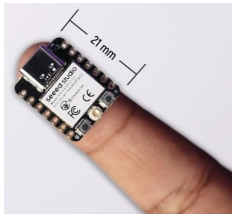
Proposed Proximity Detection and Warning System to Curb Backover Incidents

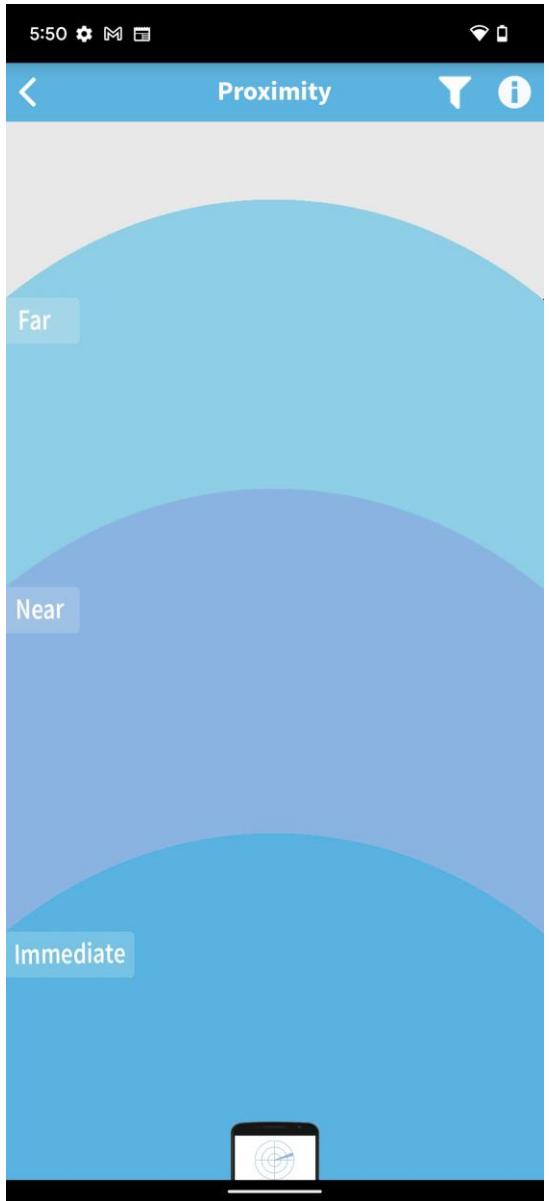
- Develop a construction and work zone safety hazard detection and alert system
  - **An in-Vehicle Detection System (iVDS):**
    - A software application
    - Mounted to heavy fleet vehicles (VPT: Vehicle Proxy Tag)
    - Detect workers or other objects in proximity to the vehicles
    - Alerts drivers when workers or objects are detected
  - **Wearable Human Tag (HT):**
    - Wearable hardware tags
    - For work crews to alert the vehicles in proximity
    - Alerts work crews with sound or vibration

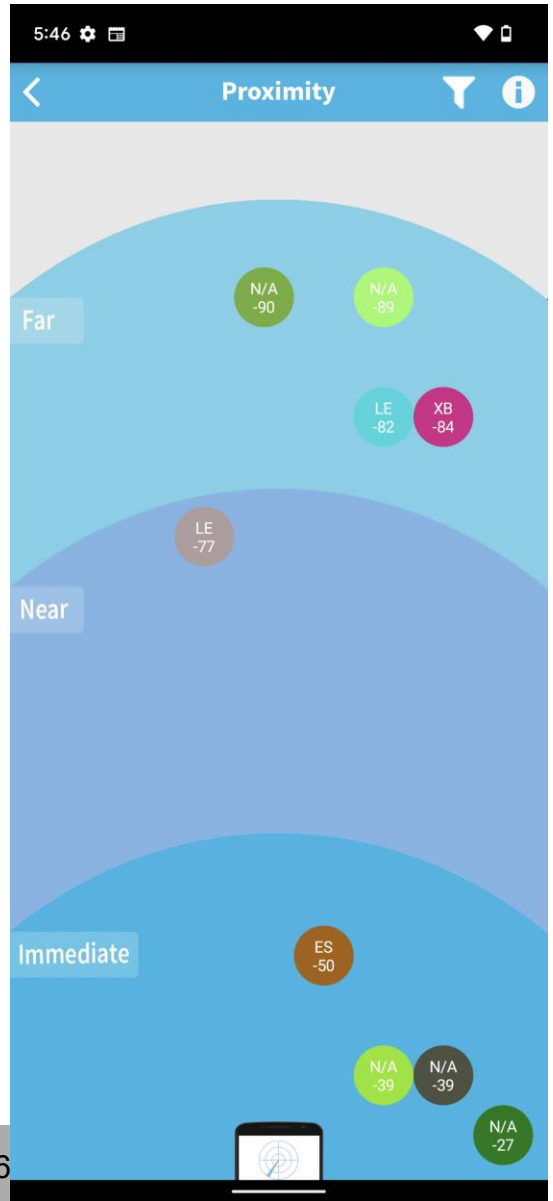


BLE Radar

- Tracking tags using the RSSI (distance) changes while backover.
- RSSI variation and noise are normalized by AI software.

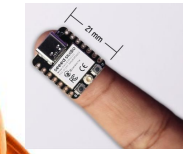


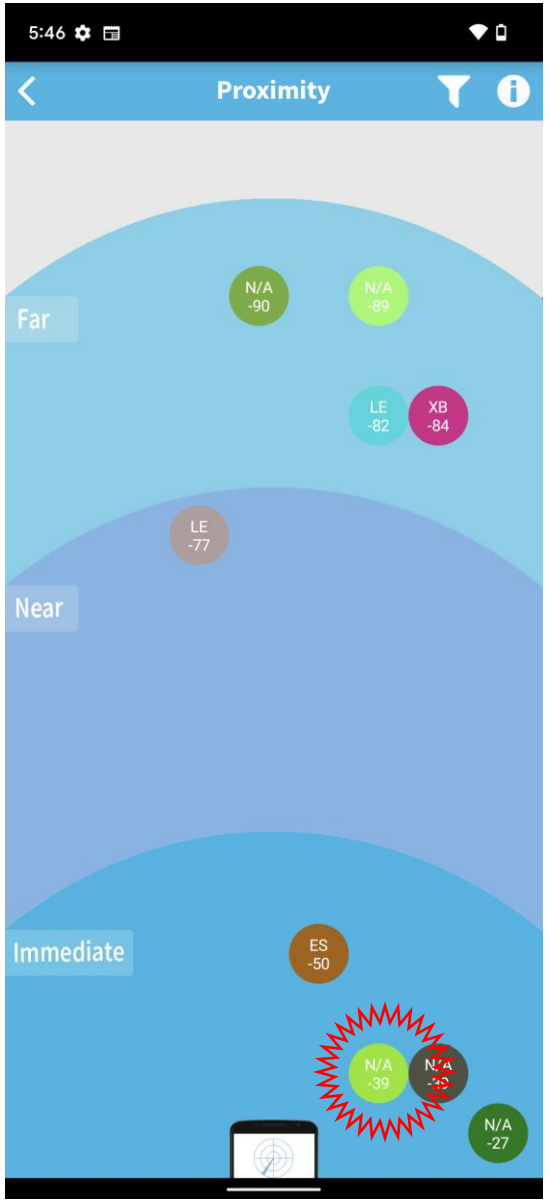




Innovations

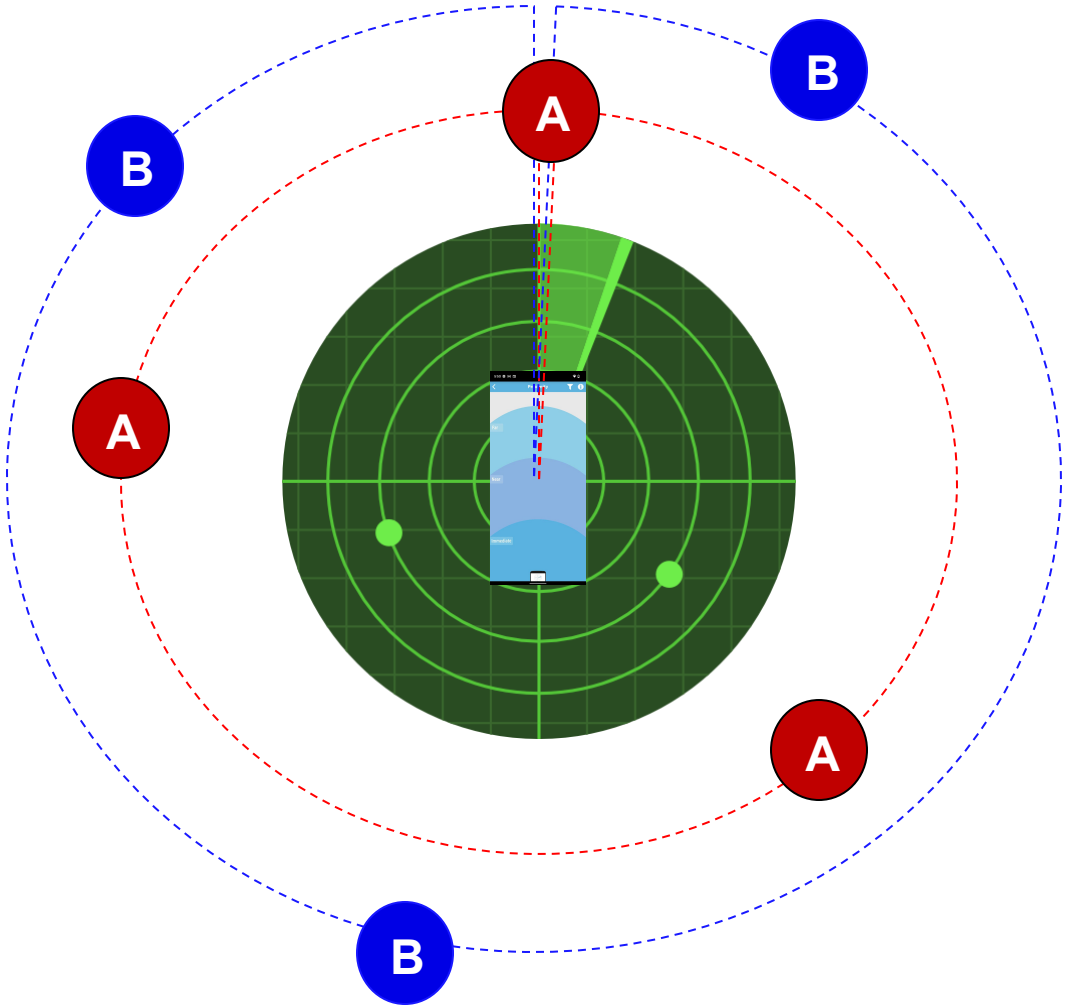
- Bi-directional Warnings
  - Warning goes to both construction workers (via tags) ar
    car drivers (via a smartphone application)
  - Improve the safety
- Ubiquitous approach
  - Cost effective
  - Easy to operate
- Intelligent SW to ensure high accuracy and precision
- No absolute location method (GPS) requirement
  - Work indoor and outdoor
  - Cost and power efficient
  - Light weight





BLE Radar

- When a truck does not move.
  - Surrounding Tags (HT) can be tracked only by the distance (RSSI)
  - Direction is not critical (Tags A and B can be anywhere on the perimeter)
  - No harm to the construction workers (Tags)



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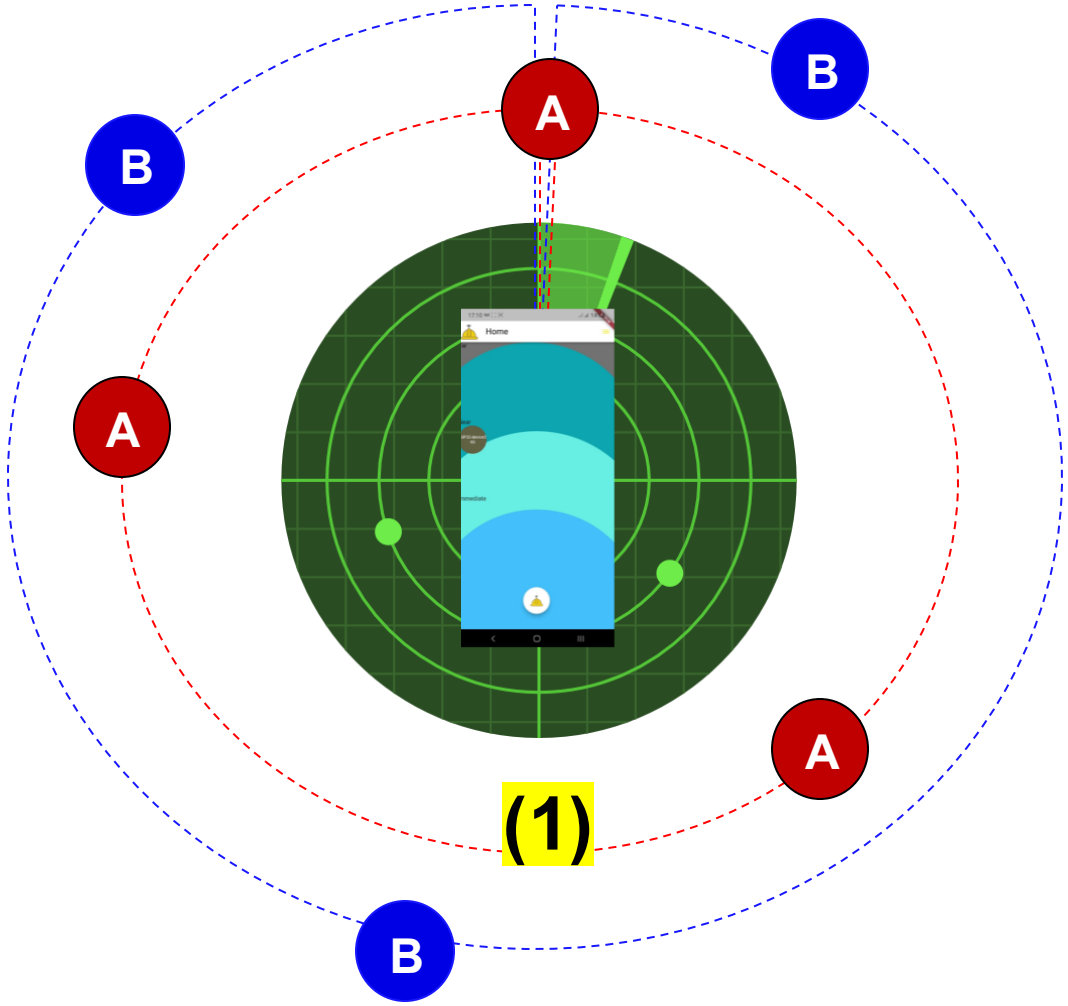
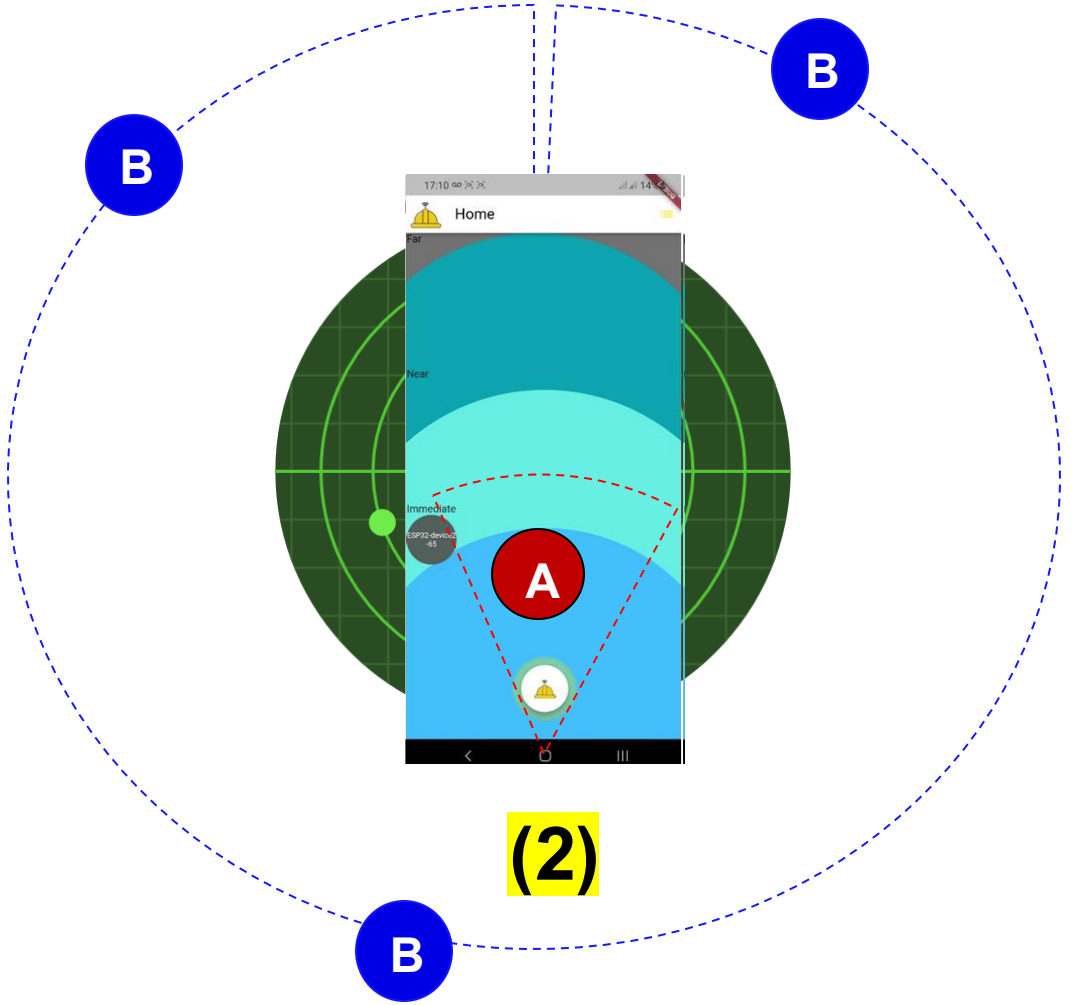
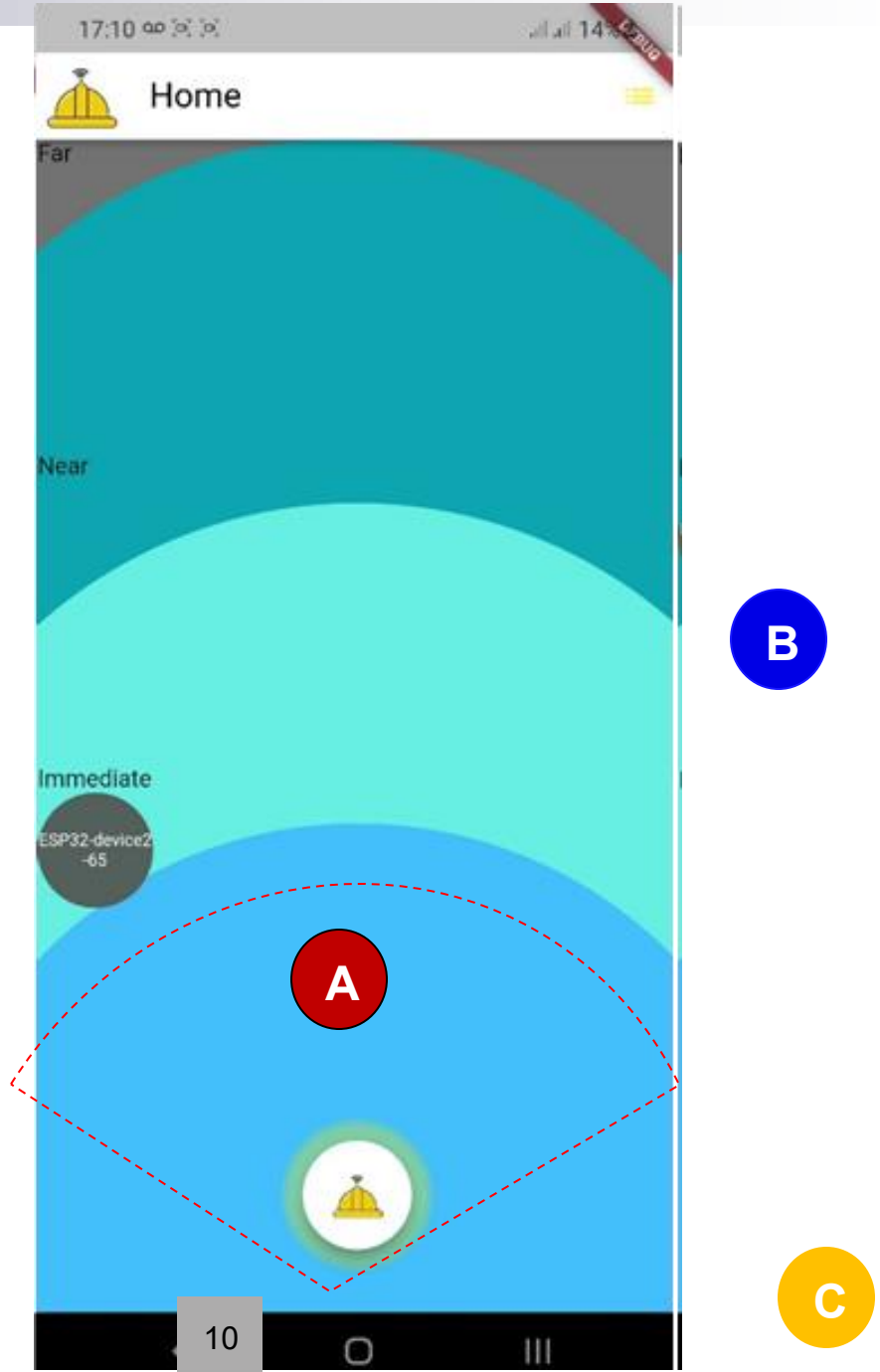




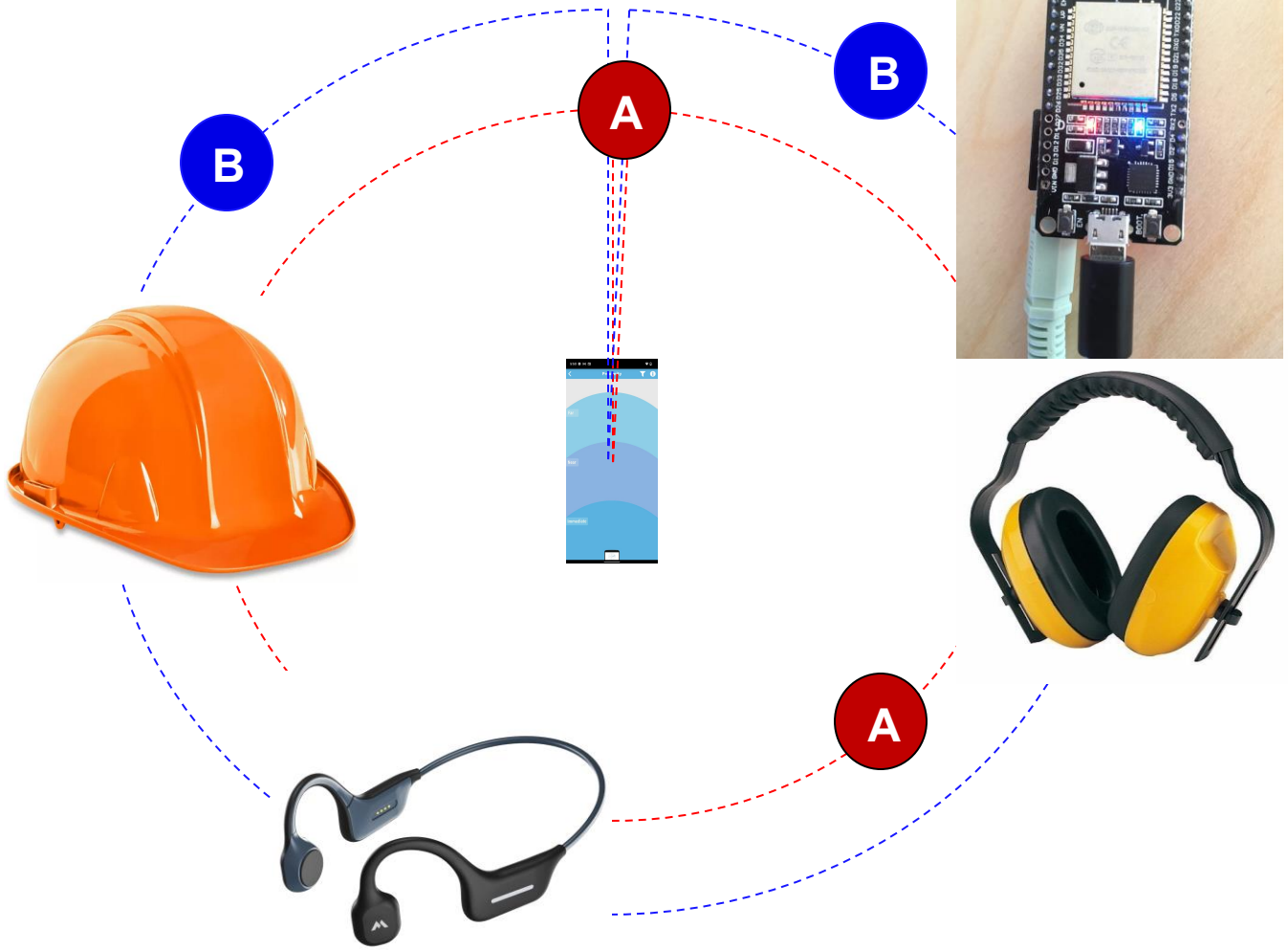
BLE Radar

- When a truck moves.
  - If the distance from a truck to a tag increases,
    - the tag is not on the moving trajectory.
    - eliminates those unnecessary tag signals.
  - If the distance from a truck to a tag decreases (getting closer each other),
    - the tag is on the moving trajectory
    - track and send a warning if tags are in a short distance.



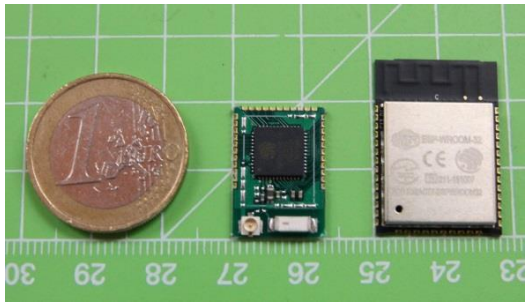
BLE Radar Development Directions

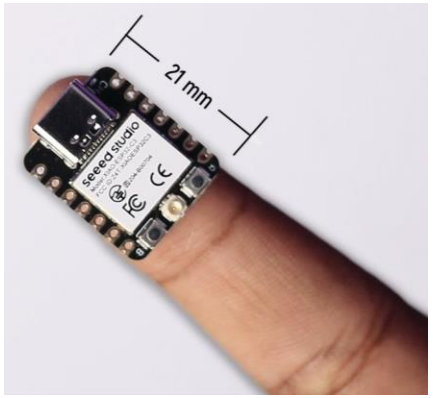
- Warning methods to iVDS.
  - Smart phone App screen
  - Voice enabled sounds
- Warning methods to HT.
  - Buzz and vibration-based warning.
  - Headphone (audio jack).
  - Bone conducted earphone (BLE).

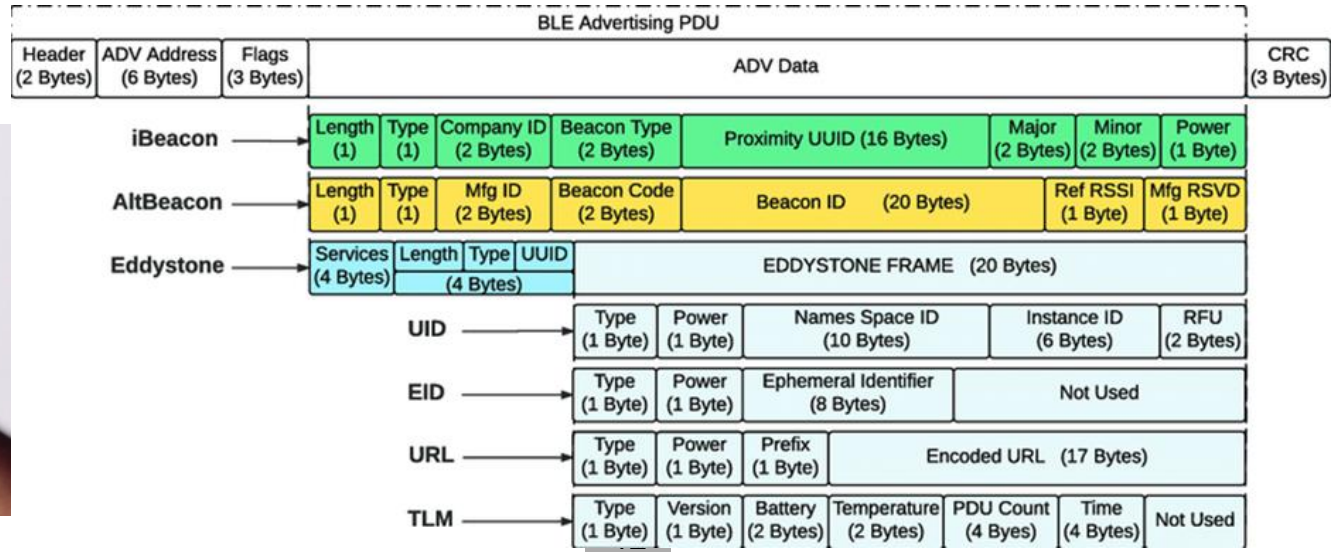


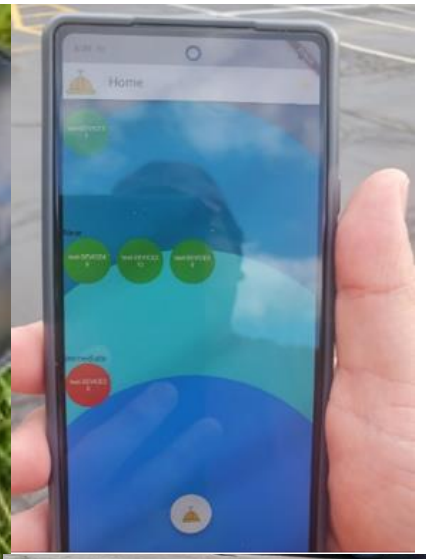
iVPD and WPS

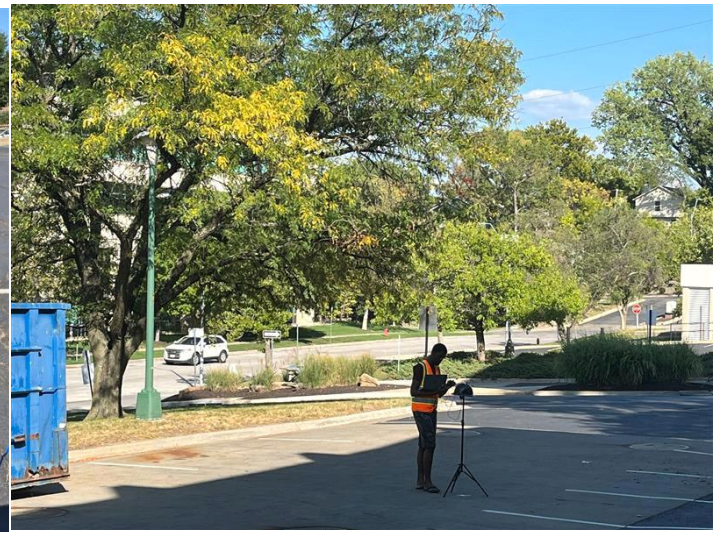
- BLE Radar
- Helmat/Headphone Harness
- Warning Systems
- Optimization (Beacon frequency, energy usage, smaller form factor, etc.)
- Control Room Option








Home

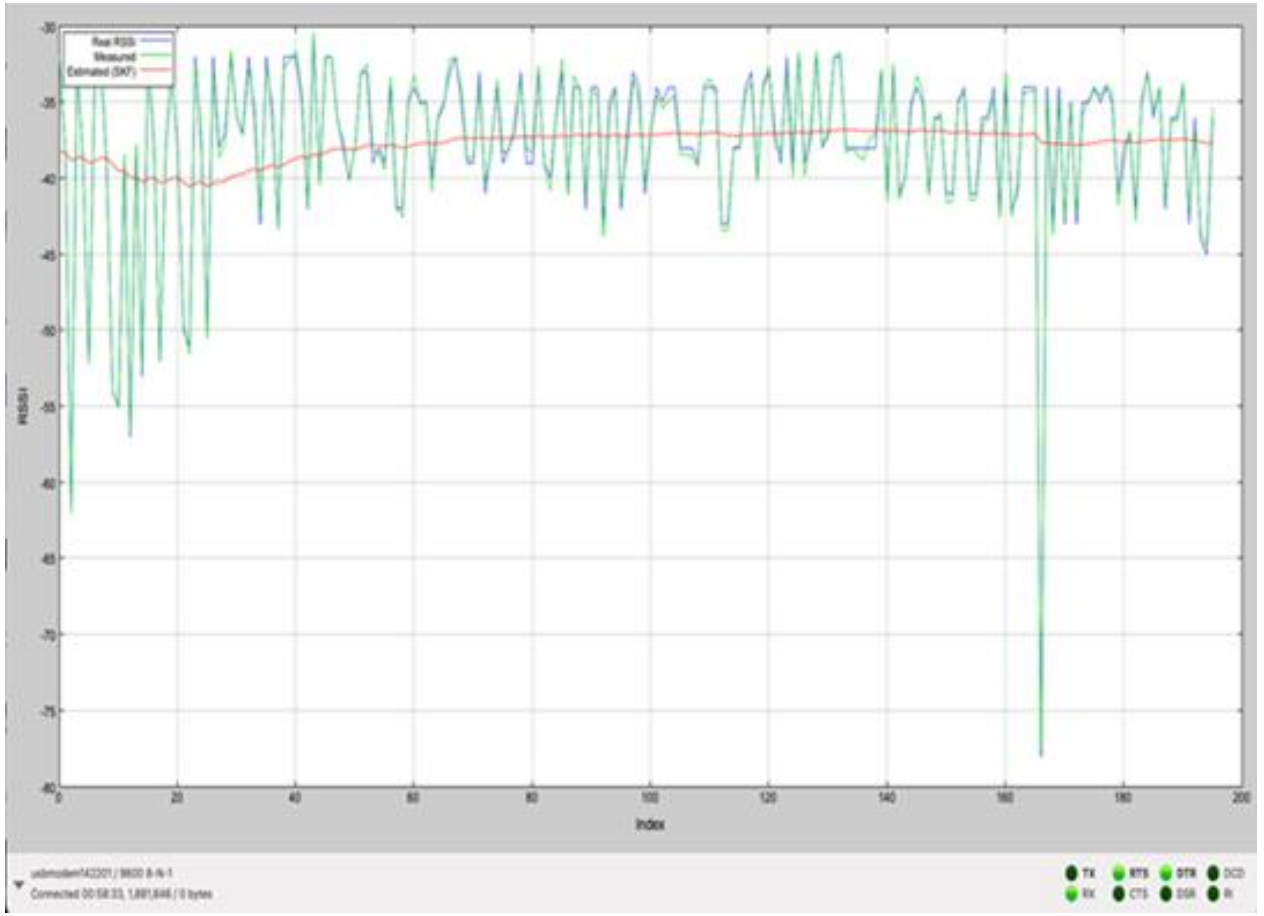



VPT
Home
iVDS
HTs (Mobile & Stable)

Measured Power or Distance Variation

The result was not unexpected, as it involved **only two BLE devices** operating outdoors amid various potentially **dynamic obstacles**.

However, our objective is **not precise distance measurement** but rather **identifying potential collision risks** to **provide early warnings** for both drivers and construction workers. A few **false positive** is allowed.



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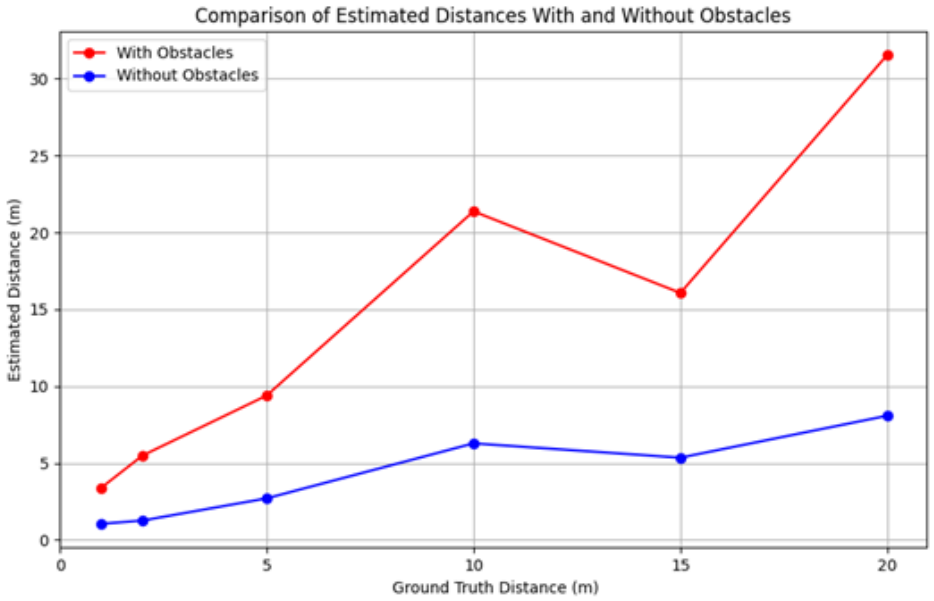
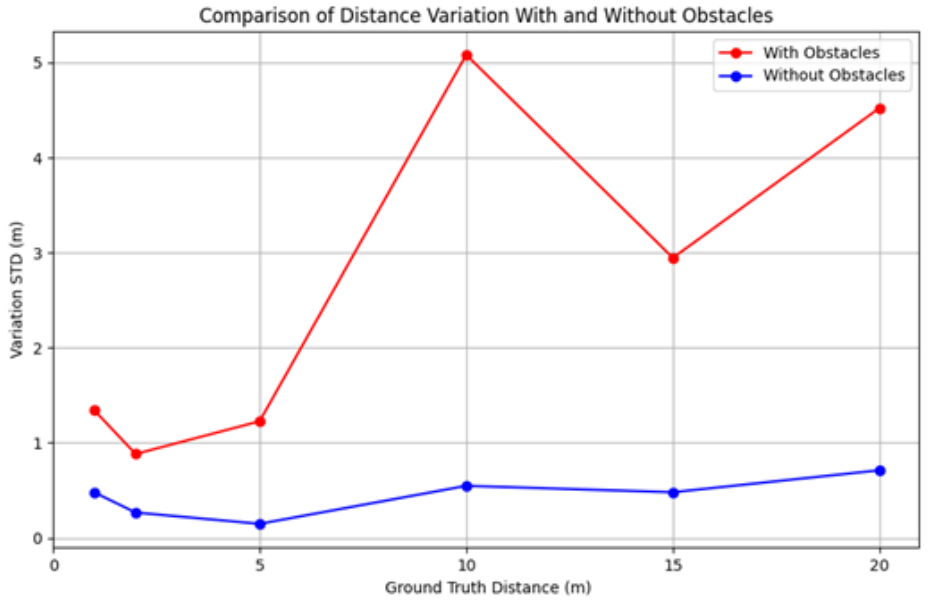
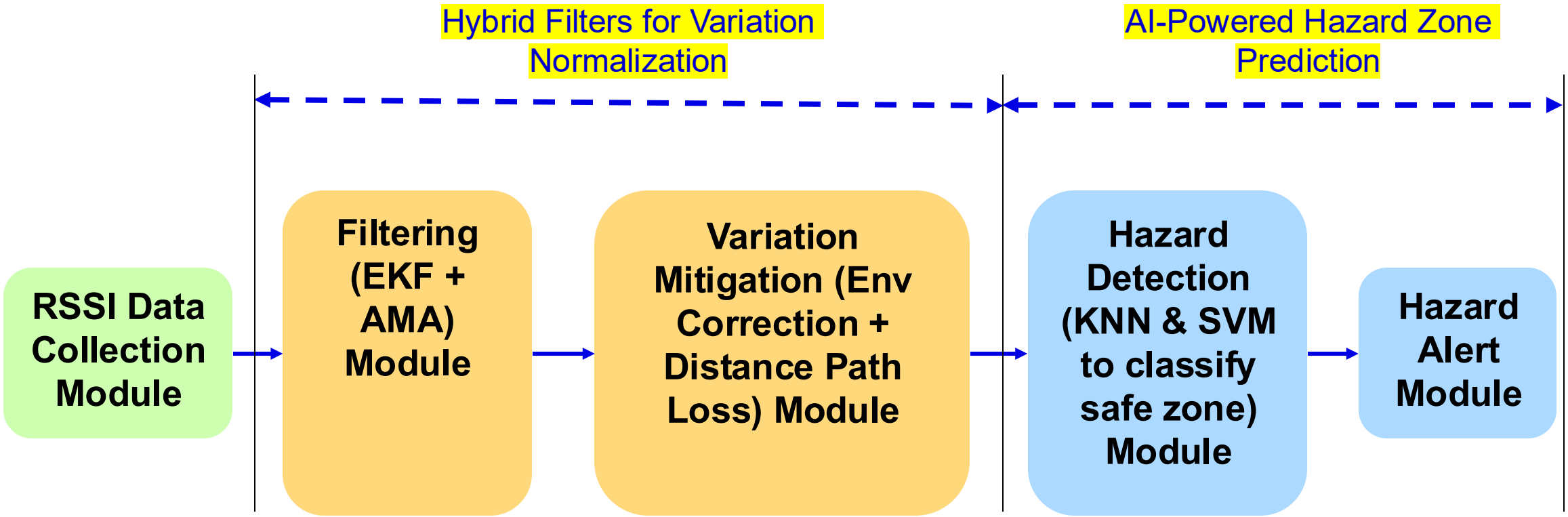
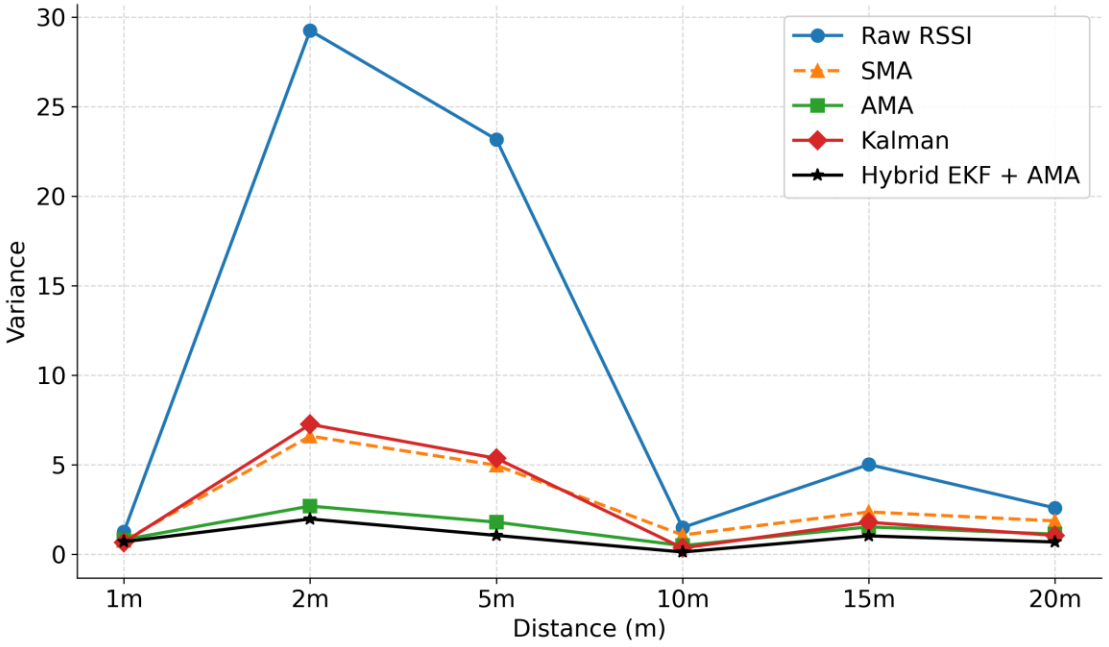


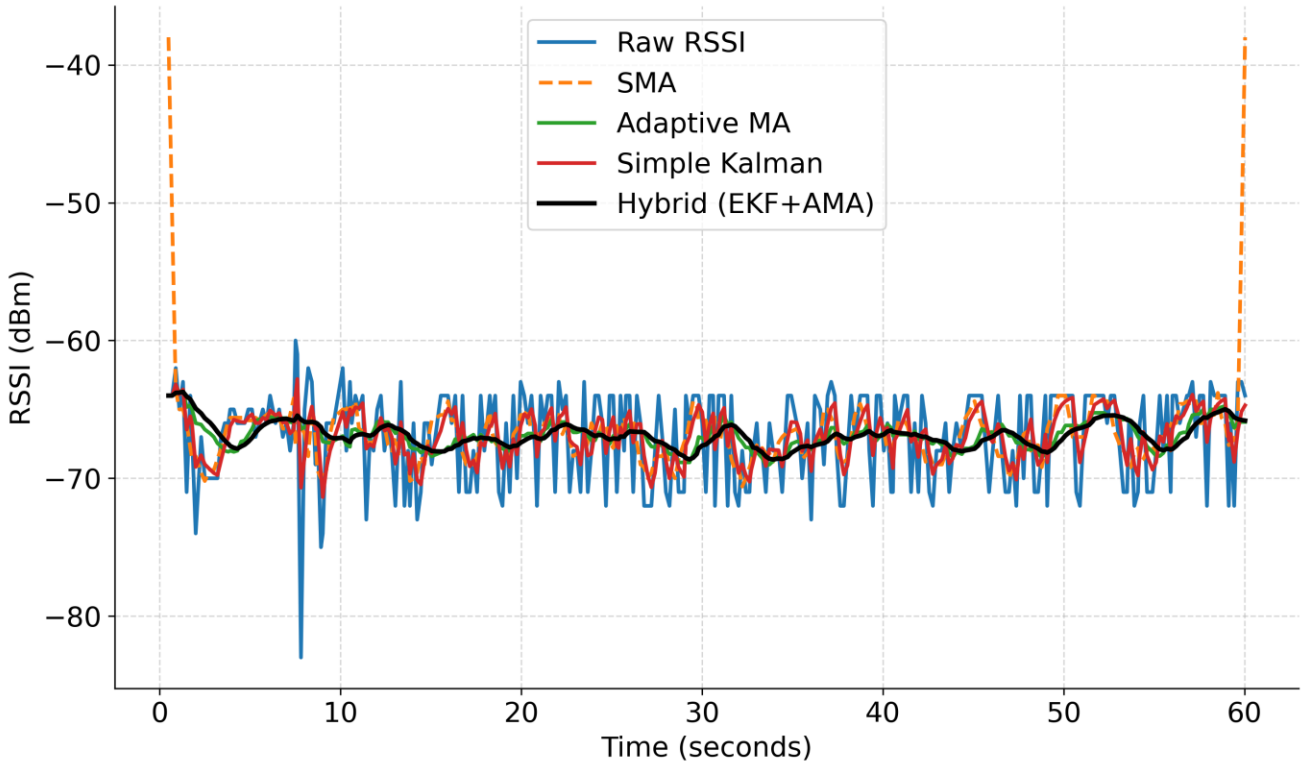


Variation Smoothing using hybrid filters (KF & Adaptive KF)
Risk Zoning using supervised AI-classification (KNN & SVM)

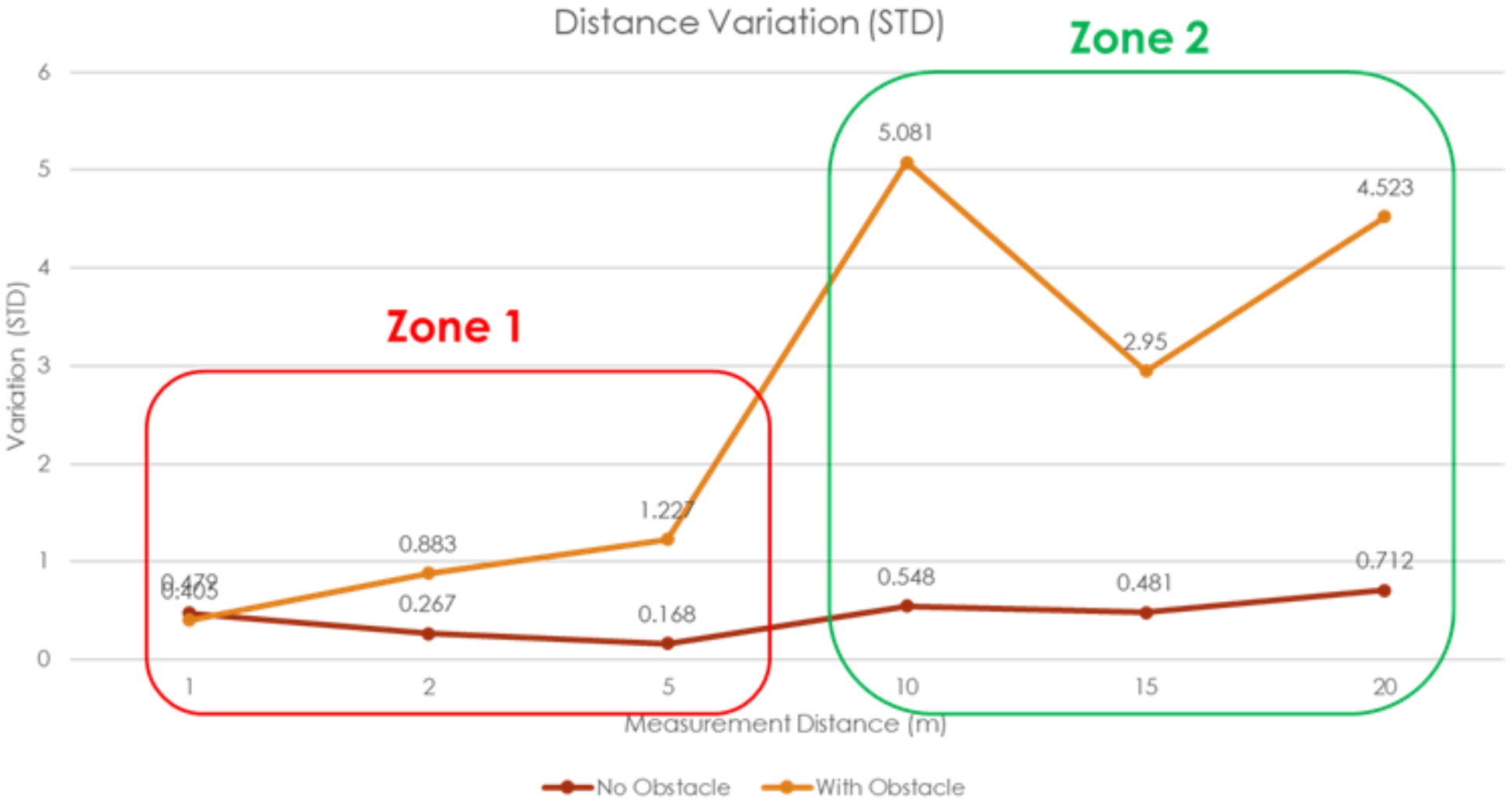
Our Approaches



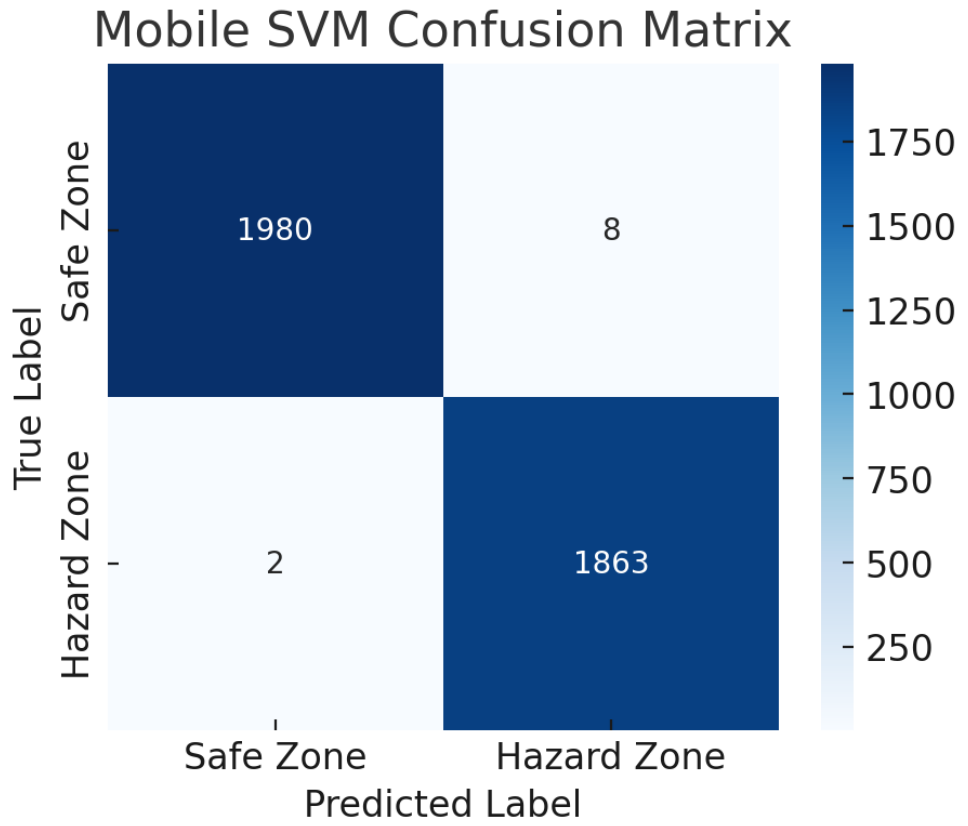




Variation results after applying various filters.



Risk Zoning with variation values



Confusion matrices (left: KNN and right: SVM) highlighting that KNN yields fewer false negatives in the Hazard class—critical for collision avoidance in dynamic environments.

Results with various approaches

COMPREHENSIVE COMPARISON OF MACHINE LEARNING METHODS FOR HAZARD DETECTION

Classifier	Accuracy (%)	Precision (%)	Recall (%)	F1 Score (%)	Training Time (s)	Inference Time (ms)	Memory (KB)
KNN	88.63	83.18	**82.74**	82.96	**0.025**	1.01	**156**
SVM	83.75	**89.13**	58.56	70.68	197.40	1.20	892
Random Forest	**89.10**	87.46	78.70	82.85	1.057	**0.52**	2,340
XGBoost	88.59	86.44	78.13	82.08	0.314	0.68	1,856