Enhanced Axle-Based Vehicle Classification Using Angle-Based Micro-Doppler Signature

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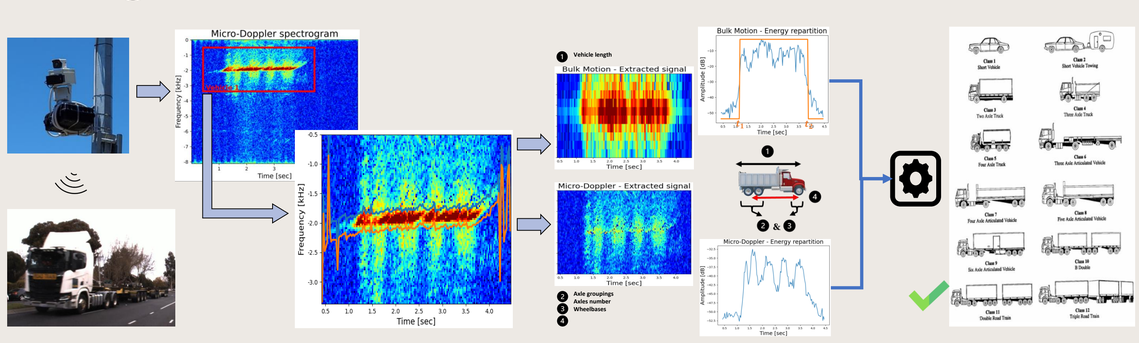
Introduction

This study introduces an angle-based micro-Doppler analysis using Frequency-Modulated Continuous Wave (FMCW) radar tailored for axle-based vehicle classification. The novel approach exploits the signal angle of arrival to separate incoming signals and noise from distinct targets.

- Multi-Vehicle Processing: Vehicle driving side-by-side can now be discriminated.
- Improved signal processing techniques enable more effective filtering out of multipath signals and clutter, allowing for more precise estimation of vehicle characteristics.
- Advance non-invasive axle-based vehicle classification through refined vehicle feature estimation.

This research advances radar-based vehicle classification by developing an algorithm that enhances the detection of multiple vehicles, improves the precision of attribute estimation, and increases the reliability of vehicle classification for more effective traffic management.

Background: Axle-Based Vehicle Classification



a) DATA COLLECTION

b) MICRO-DOPPLER COMPUTATION & SPECTROGRAM SIGNAL LOCALISATION

c) VEHICLE SIGNAL SEPARATION

d) VEHICLE FEATURE ESTIMATION

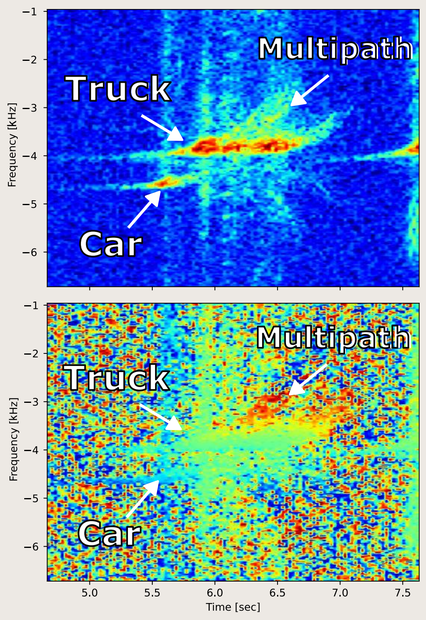
e) VEHICLE CLASSIFICATION

Application Limitations

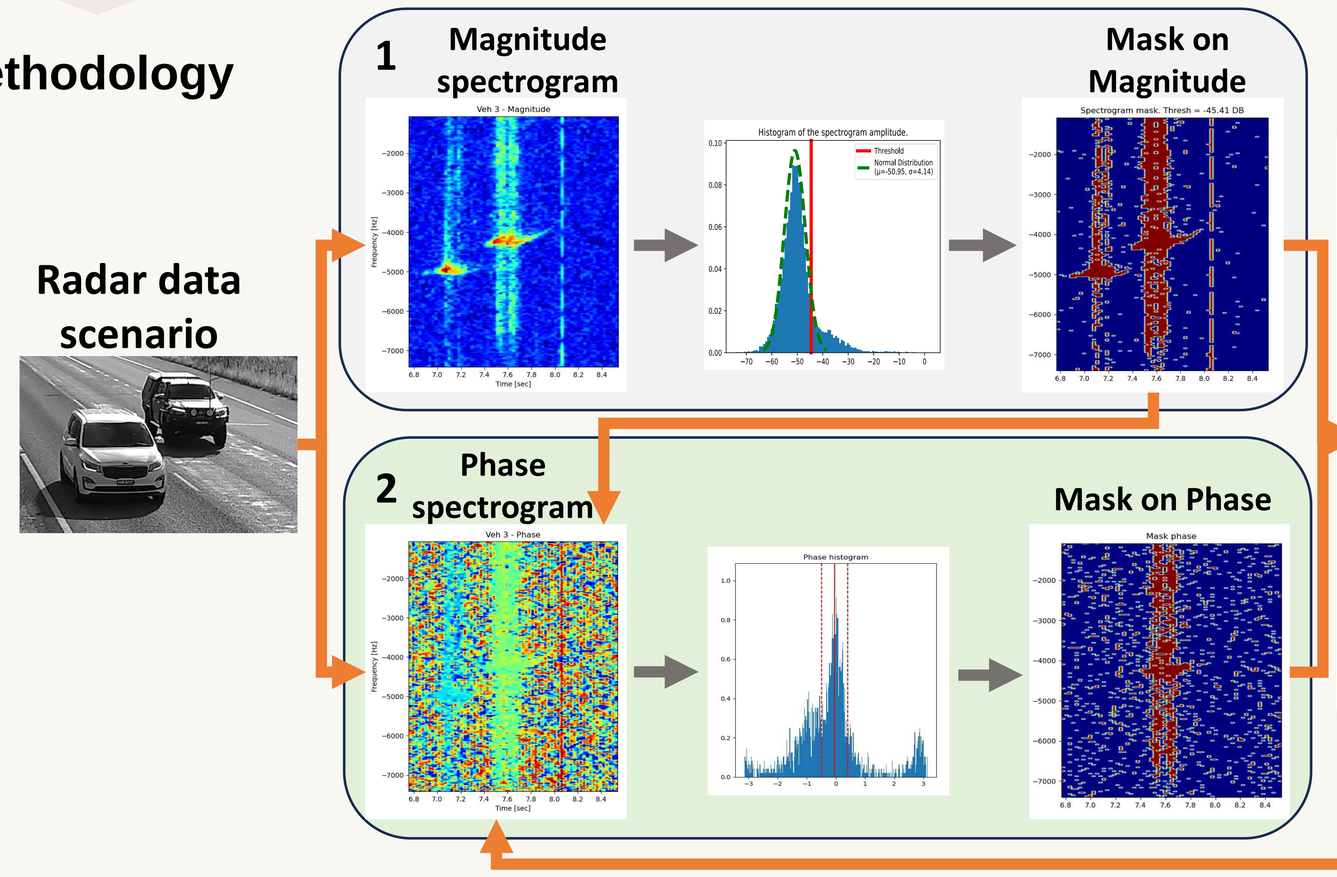
- Tangled Signal
- Presence of Noise/Multipath/Clutter

=> Vehicles not processed, which reduces the performance of axle-based vehicle classification.

Objective: Utilise direction of arrival to distinguish vehicles with overlapping signals in the spectrogram and mitigate multipath effects, thereby enhancing the vehicle classification algorithm's accuracy.



Methodology



1 THRESHOLDING ON THE MAGNITUDE SPECTROGRAM

Isolate the target signals from the background noise in the amplitude spectrogram by thresholding based on the noise amplitude.

$$M_{mag}[l,f] = \begin{cases} 1 & \text{if } \mathcal{Z}^m_{\text{mag}}[l,f] \geq T_{mag} \\ 0 & \text{if } \mathcal{Z}^m_{\text{mag}}[l,f] < T_{mag} \end{cases}$$

After computing threshold T_{mag}, mask M_{mag} is applied to the phase spectrogram, isolating the signal points for extraction.

2 THRESHOLDING ON THE PHASE SPECTROGRAM

To isolate the phase values specific to an individual vehicle, a mask determined from the magnitude spectrogram is applied to the phase spectrogram. A histogram is then generated, and the Mode M, along with a predefined $\Delta M = 0.45$ rads informs the computation of a secondary mask M_{ph}, that delineates the vehicle's phase values within the spectrogram.

$$M_{ph}[l,f] = \begin{cases} 1 & \text{if } M - \Delta M \leq \mathcal{Z}^m_{\text{ph}}[l,f] \leq M + \Delta M \\ 0 & \text{otherwise} \end{cases}$$

3 SIGNAL SEPARATION FOR VEHICLE CLASSIFICATION

The target vehicle's signal is isolated using mask M_{Veh}- intersection of the magnitude and phase masks:

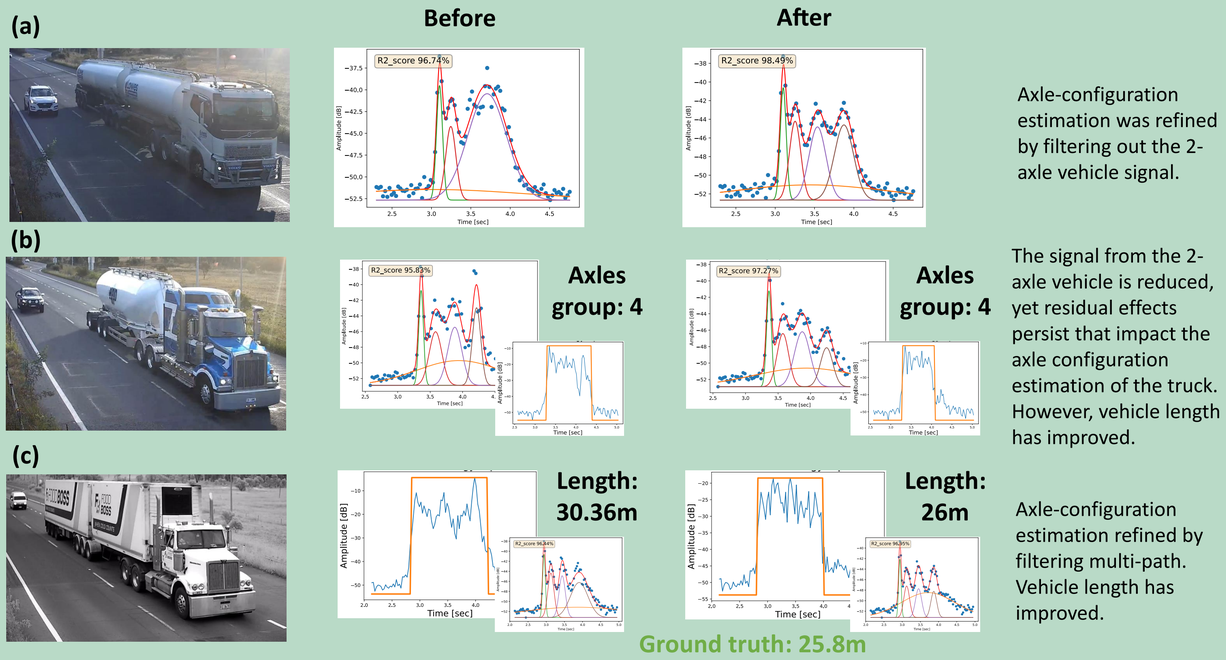
$$M_{Veh}[l,f] = M_{Mag}[l,f] \wedge M_{Ph}[l,f]$$

Residual signal obtained from mask R_{veh}:

$$R_{veh} = M_{Mag}[l,f] \wedge \neg M_{Ph}[l,f]$$

The residual signal is replaced with noise for vehicle classification but may be reprocessed for secondary target processing.

Results



Axle-configuration estimation was refined by filtering out the 2-axle vehicle signal.

The signal from the 2-axle vehicle is reduced, yet residual effects persist that impact the axle configuration estimation of the truck. However, vehicle length has improved.

Axle-configuration estimation refined by filtering multi-path. Vehicle length has improved.

Ground truth: 25.8m

- Reduction of Clutter and Multipath
- Improvements of vehicle features estimation using the radar algorithm
- Increase of detection rate (+0.2%) and classification accuracy (+6%) based on 57 vehicles.

Conclusion

- This research develops signal processing methods that improve radar-based extraction of vehicle features, facilitating vehicle classification and enabling analysis in multi-vehicle scenarios.
- It improves accuracy and detection rate in an existing axle-based vehicle classification algorithm by differentiating vehicles based on the angle of arrival.
- It facilitates non-invasive, axle-based vehicle classification using radars, promoting efficient traffic data collection methods for road authorities.

Limitations and Future Directions:

While effective, the method does not completely eliminate residual clutter signals, which may impact the accuracy of axle configuration estimation. Future work will focus on refining the signal processing algorithms to address these challenges, aiming to eliminate the influence of clutter and further refine the system's ability to classify vehicles in complex driving scenarios accurately.

References

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