Spatially Distributed Collaborative Automotive Radar

Project within FFI
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Content

FFI in short

FFI, Strategic Vehicle Research and Innovation, is a joint program between the state and the automotive industry running since 2009. FFI promotes and finances research and innovation to sustainable road transport.

For more information: www.ffisweden.se

1. Summary

This project investigated the potential of a distributed collaborative, non-coherent, radar network, where a number of cars in close vicinity in an urban environment are connected in a random fashion to such a radar network and share their radar data on a low level. The spatial diversity of such a radar network has potential to dramatically improve situational awareness, better object classification, early warning, and finally accident mitigation or impact reduction. The combining of radar data is based on low level fusion to keep as much information as possible from the individual radar systems, and the combined information is intended to be distributed to all nearby cars. The concept intends to utilize state-of-the-art radar sensors, i.e. does not require to build or install any new hardware, but requires interconnectedness of cars by low-latency/high-data rate 5G/6G communication links.

The purpose of this pre-study was to investigate and to benchmark the radar data improvement and thus situational awareness of such a radar network as compared to a single radar system. This was done by collection of measurement data in multiple scenarios at the vehicle safety test track of the consortium partner AstaZero, using car radars by the consortium partner SafeRadar and using statistical signal analysis methods by the consortium partner KTH.

Additionally, to address the challenge with object classification, investigations on how to produce accurate annotations on the data was performed by consortium partner Semcon, by using publicly available car radar datasets.

The project concluded on the benefits and a requirement analysis for implementing such a radar network in a dynamic and real-world scenario. Particularly, time-synchronization and pose estimation of the sensors are critical factors that influence the potential. Furthermore, standardisation of data format to allow data sharing between different vehicle and sensor manufacturers is a key-activity for large-scale roll-out and utilization of this type of radar network.

2. Sammanfattning på svenska

Det här förstudieprojektet syftade till att undersöka förbättringen i förståelse av en trafiksituation då information från ett flertal radarsensorer monterade på olika fordon kombineras genom att forma ett spontant nätverk. Mer än ett fordon kan då utnyttja den bästa mätinformationen som fås exempelvis från den sensor med bäst mätgeometri eller den enda mätinformationen då andra sensorer är skymda. För att få ut det mesta möjliga från varje tillgänglig sensor fusioneras data på låg nivå, dvs före eventuella tidsfiltreringar.

Inom projektet samlades data in för flera scenarier på en provbana. Denna data analyserades med statistiska metoder. De grundläggande förväntningarna kring förbättringspotential bekräftades och ett antal frågor och områden för framtida arbete identifierades. Vidare studerades inom förstudien hur radardata från flera fordon effektivt kan annoteras för att effektivisera utvecklingen av ett distribuerat fordonsnätverk.

Baserat på resultaten från förstudien har ett fullskaligt projekt definierats.

3. Background

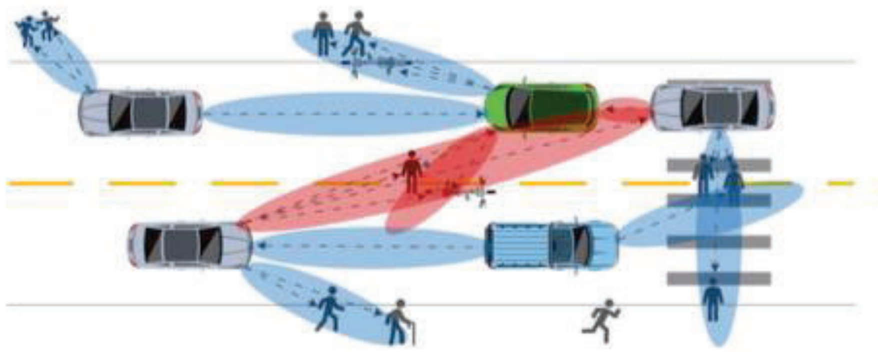
Sweden has traditionally been strong in signal & data processing, microwave and radio producing large companies with products such as microwave communication links and radar for defense applications from Ericsson and Saab. Some of this key competence exists within the consortium. This project proposes to build and strengthen this competence applying it to new emerging commercial markets for enhanced traffic safety, in particular for urban environments, and vehicle to vehicle communication. This will facilitate autonomous driving, vehicle to vehicle communication and AI development of novel classification frameworks.

If the project is successful, and the results are implemented on a large scale, the overall situational awareness of cars ADAS would be increased significantly. This would improve the probability of detecting people and other vehicles significantly, which in turn may reduce the amount of injuries, deaths and property damage in traffic.The results could potentially be implemented on stationary sensors as well, which could monitor e.g. zebra-crossings. This would further increase the situational awareness shared between vehicles, and allow for safe and comfortable braking if there are people on the crossing, without just relying on a single vehicle's built-in sensors.

According to several reports from Folksam, about 70-80 % of car to pedestrian accidents occur after sunset in urban and suburban environments. Using a spatial collaboration of automotive sensor data, the situation awareness and safety increases and these situations can be prevented. In addition to this, the sensor data can also be used for traffic planning where the safety of intersections can be enhanced. As people are not identifiable in radar data, there are no issues with compliance to privacy regulations such as GDPR.

4. Purpose, research questions and method

The purpose of this pre-study was to investigate and to benchmark the radar data improvement and thus situational awareness of a radar network as compared to a single radar system.



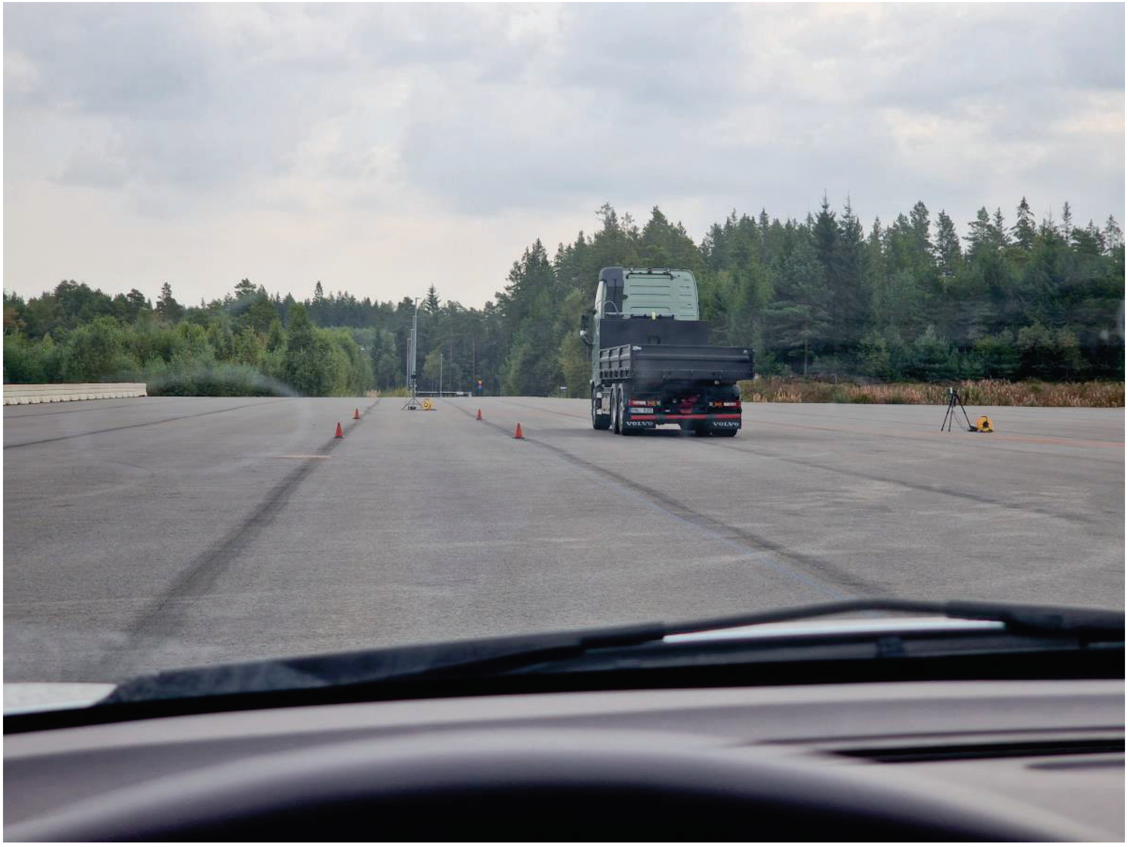
Within the project, radar data was collected in multiple scenarios at a vehicle safety test track using car radars. The collected data were analysed by statistical signal analysis methods.

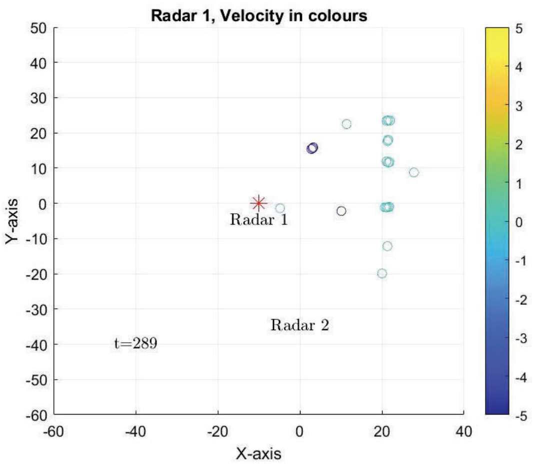
5. Objective

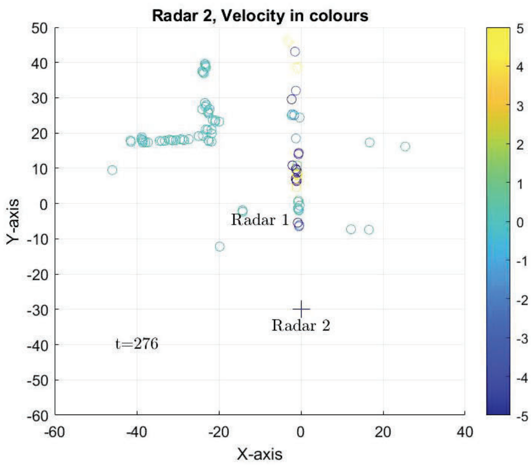
The pre-study aimed to give sufficient knowledge of the potential and challenges so that a precise definition of a full-scale research project would be possible.

6. Results and deliverables

The figures below show some of the results from one of the test scenarios. A car drives close to a stationary truck which obscures the line of sight for one of the radars. The second radar also has a more favorable measurement geometry since the reflections from the moving car have negative Doppler shift as the car approaches it. In this test-scenario, both radars were stationary.







In the radar data, it can be observed how only the second radar can measure the moving car for some time, and how it through the scenario better estimates the velocity of the car. In such a scenario, a vehicle driving through the position of the first radar can utilize information from the second radar to become aware of the imminent collision threat and act in time to avoid the collision.

Annotation of data

All datasets use complementary sensors to annotate the radar data and are hence reliant on extrinsic calibrations and time sync between sensors. The K-Radar is the only dataset that has annotations in adverse weather or light conditions where the lidar fails to produce useful data. They however mention on their webpage [1] that their trained radar detector performs robustly in adverse weather conditions even when only trained on data from clear weather conditions and argues that the detectors abilities depends more on road conditions than weather conditions and hence could be trained on only clear weather annotations.

The different annotation pipelines seem to be almost as many as the datasets. For category labeling most however seem to rely on camera images or image detectors such as Mask R-CNN or Retina Net, however the proposed heuristic auto annotation process in the K-Radar uses only the lidar detector PVRCNN++. The CARRADA annotation process is not generally applicable as it relies on knowing the elevation of detected objects.

The placement of the sensors in the different datasets differs and could have implications on annotation processes. For example in the K-Radar, RADIal, TJ4DRadSet and VOD the radar is placed on the front bumper of the car and the complementary sensors on the roof which theoretically could result in scenes where the radar signal is blocked by some object meanwhile the camera or lidar has a free visual path to the object resulting in annotation of radar data where no actual information of the object exists. Or the other way around where no annotation is created but information of the object exists in the radar data. Additionally, in the RADIal and CARRADA the radar field of view is larger than the cameras and they could therefore not annotate all objects in the radar data.

Vehicle to vehicle collaboration might offer improved annotation capabilities

There are some inherent limitations of using complementary sensor data to annotate another sensors data. For example, a radar detector trained on automatically generated annotations from one camera detector will at best perform equally good as that camera detector if the sensing environment is the same as during the training data. This can be understood by considering the training process, which will be to get the radar detector to mimic the camera detector as good as possible. To overcome this, collaboration with detections between vehicles could help. For example the figure 9 shows a scenario where two radar+camera sensor watches a scenario from two different viewpoints. Here there exists more data and hence using all the data to produce annotations would allow but not guarantee the radar detector to possibly outperform the single camera detector. This however adds a lot of additional challenges with time syncing of sensors on different vehicles and standardized communication protocols.

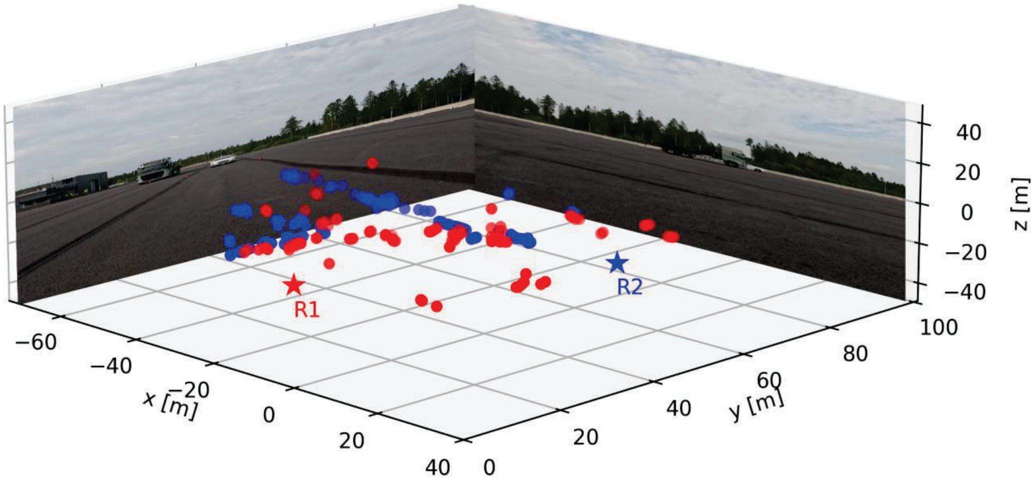


Figure: A scenario covered by two radar+camera sensor setups. Red and blue stars represent radar+camera positions and the dots the point cloud generated from the radar data.

7. Dissemination and publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	x	Pre-study results and full-scale project content have been shared and discussed with three Swedish OEM:s.
Be passed on to other advanced technological development projects	x	The result is the basis for a full-scale project definition.
Be passed on to product development projects	x	The radar signal processing was improved based on results achieved from the test-track data.
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions	x	

7.2 Publications

No publications yet.

8. Conclusions and future research

Based on the results of this pre-study, a full-scale 2 years project has been defined. The idea is that the project will address the following issues:

- Decentralized approach: distributing data, processing data
- Time synchronization
- Car positioning, car orientation

For efficient execution of the project, a vehicle manufacturer is needed as a project partner as there are many vehicle platform topics to be solved before the research questions can be addressed.

Other topics to be addressed in the future and that were found during the pre-study are:

- Local ad-hoc network management
- Optimization of radar data to be distributed
- No available standards

9. Participating parties and contact persons

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