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Development of Detection Techniques for Millimeter-Wave Radar Using DIVP Simulator

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Object detection's performance in various environmental conditions is the key point for the recent interest in automotive radar sensors. The radar has many drawbacks related to its data sparsity, which cause some difficulties in object clustering, tracking, and classification. This paper exploits the Driving Intelligence Validation Platform (DIVP), which emulates the behavior of Millimeter-Wave radar to develop the design of the classical algorithms. The various platform scenarios with pedestrians, cyclists, and cars offer a variety of new possibilities to generate techniques with higher performance. The results analysis illustrates the fidelity of the DIVP and its role in improving approaches' performance.

There is a huge recent interest to build radar simulation frameworks to generate arbitrary traffic scenarios with reflection models for pedestrians, bicycles, and vehicles. The radar modeling requires a complicated simulation of a grouping of radar reflections that belong to the same object. Though, the simulator can enhance the accuracy of detection and recognition algorithms in real life even with models' uncertainty. This paper presents a comprehensive analysis of the DIVP simulator results with developed clustering, tracking, and classification approaches. Simultaneously, it compares the results of the simulator and the available measurement data to approve the simulator fidelity.

The proposed clustering algorithm is an adaptive region-based Dbscan approach, whose parameters such as maximum threshold value "ϵ" and the minimum number of points "$minpts$" are estimated as linear functions of the range. Both spatial distance and the radial velocity are combined with scaling in a single Euclidean distance to estimate the margin of the maximum threshold ϵ_{xyv_r}.

$$\sqrt{\Delta x^2 + \Delta y^2 + \Delta v_r'^2} < \epsilon_{xyv_r} \quad (1)$$

The value of "$\Delta v_r'$" is estimated by scaling the velocity difference "Δv_r" to the same scale for the spatial difference $\sqrt{\Delta x^2 + \Delta y^2}$.

The adaptive region-based algorithm divides the whole range into many regions with fixed step sizes but with overlapped areas. The overlapped areas increase the possibility to acquire more target clusters with the higher regions without any relaxation in the parameter relations that may increase the clutter clustering. The implemented tracking approach in this paper is the global nearest neighbor (GNN) with the extended Kalman filter and interacting multiple models (IMM).

The exploited classification approach is the bidirectional long short-term memory (Bi-LSTM) for four various classes: vehicles, bicycles, pedestrians, and noise. It utilizes ten sequential point cloud maps of radar reflection maps as input features by using three various types of extracted class features with class positions. The first type is a raw point cloud map ("Raw map") with a size of 40x40 pixels around the weighted mean of the class with a step size of 0.1 m. The second type is the handmade feature amounts for point cloud ("Handmade"), which are the number of class points, standard variation of X and Y positions, and maximum and standard variation of the power intensity. The third type is using only the maximum reflection intensity feature ("Max I"). The first step in the classification process is to achieve the results by using simulator data and measurement data separately with randomly split into 80% of the training dataset and 20% of the evaluation dataset. The final step is to investigate a comprehensive analysis of the accuracy of the integrated simulator and measurement datasets in classification. The training data is all simulator datasets with various mixing rates of the measurement data that are chosen randomly. For cross-validation, all measurement data excluding training data is tested at the rate of 0 to 80 % as shown in Fig. 1 for the three kinds of feature approaches.

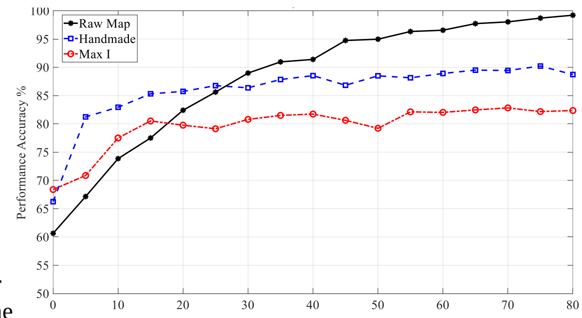

Fig. 1 Classification accuracy with various percentages of measurement data for the different approaches: "Raw Map", "Handmade", and "Max I".

This paper illustrates that the clustering F1-score exceeds 90% for both simulator and measurement data by clustering approach whose parameter relations with range are estimated based on the simulator data alone. The classification results indicate that the current modeling for radar data may not be highly precise; however, the results are fairly satisfying, especially when incorporating a small portion of the measurements into the training data. The integrated classification accuracy for the "Homemade", and the "Max I" approaches is barely worse than the training with only experimental data due to the differences between the simulator model and the experimental data. Though, the integrated accuracy can even exceed the accuracy of using only measurement data up to more than 99% for the "Raw map" classification as shown in Fig. 1. The incorporation of the simulator dataset also enhances the viability of classification by increasing the number of samples without complicated measurement procedures. In the future, the tracking algorithms will be enhanced for complicated scenarios to be exploited in the sequential point cloud of radar reflection for classification.