A Novel Point Cloud Generation Method based on Monocular Images and FMCW Radar

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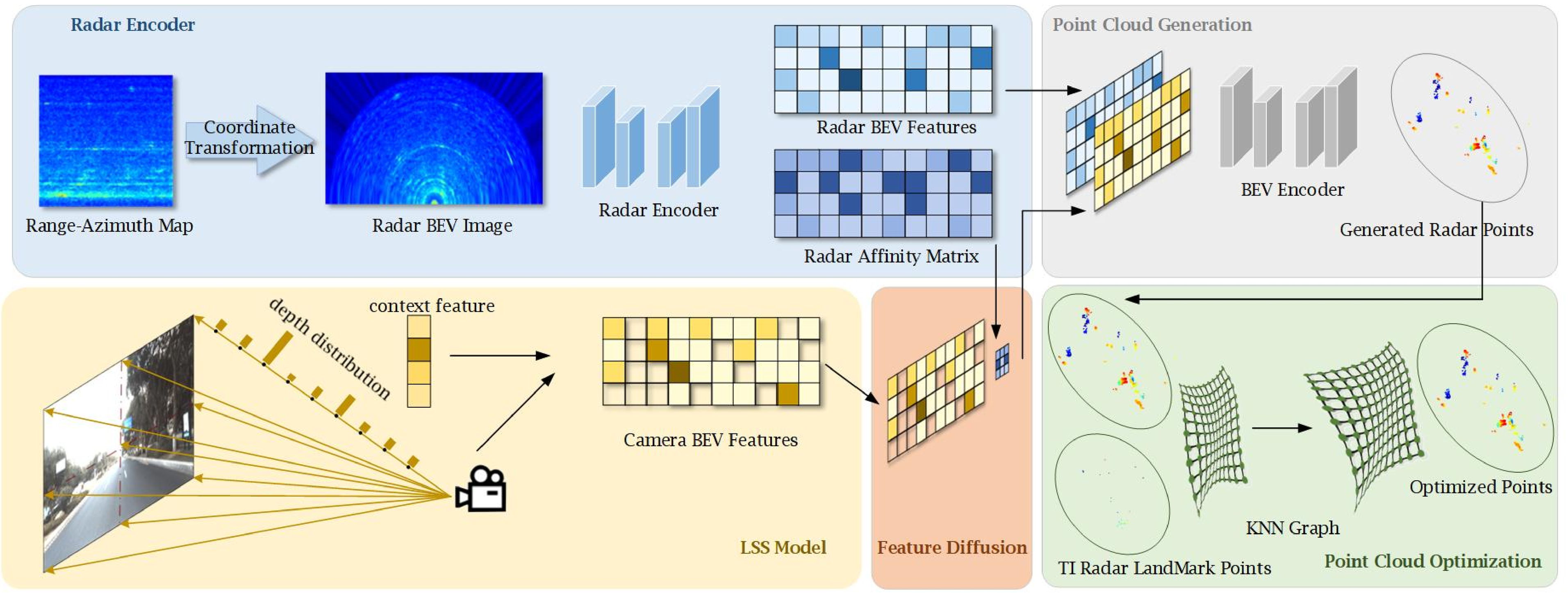
Introduction:

- In recent years, 77GHz millimeter wave radar technology has rapidly emerged as a cost-effective alternative for advanced driver assistance systems. This technology is used for various applications, including autonomous emergency braking and adaptive cruise control. Furthermore, millimeter-wave radar is highly robust in different lighting and weather conditions and provides accurate measurements of distance, azimuth, and instantaneous velocity.
- However, unlike LiDAR point clouds, typical millimeter-wave radar point clouds have four limitations:
  - Sparsity
  - Limited vertical field of view
  - Clutter points
  - Viewpoint variation and temporal variation
- The aim of our work is to generate high-quality millimeter-wave radar point clouds for autonomous driving scenarios. To this end, we propose a novel method that combines camera and millimeter-wave Radar BEV images to produce superior millimeter-wave radar point clouds. Our approach consists of three modules: **Hessian matrix based peak enhancement (HPE)**, **Affinity matrix based BEV feature diffusion (AFD)**, and **graph based point correction (GPC)**.
- In addition, we introduce a new evaluation metric specifically designed for evaluating the quality of millimeter-wave radar point clouds in autonomous driving perception tasks. To validate the proposed method, we construct a real-world dataset, including urban streets, elevated highways, and tunnels. Experiments demonstrate that our approach outperforms existing methods, resulting in fewer clutter points and denser real point clouds.

Our Methods:

- Our proposed method involves several steps to generate a high-quality pseudo radar point cloud for autonomous driving scenarios.
- **HPE Module:** we convert the range-azimuth heatmap (RAM) into radar BEV images, and enhance them using the Hessian matrix to improve the target reflection intensity. Additionally, we generate BEV representations from the monocular images using the LSS model.
- **AFD Module:** we feed the radar BEV images into the radar encoder to obtain the radar encoded features and radar BEV affinity matrix. The latter can complete the sparse monocular BEV features. We then combine the monocular BEV features with the radar BEV features and pass them to the BEV decoder to generate the pseudo radar point cloud.
- **GPC Module:** we optimize the pseudo radar point cloud using KNN graph with radar ground-truth points to achieve better accuracy and density.



Experiment Results:

- High-quality point clouds are essential for autonomous vehicles. Our goal is to make the radar point clouds closer to the LiDAR point clouds. Therefore, we use the LiDAR point clouds as the ground truth and introduce a new evaluation metric to evaluate the quality radar point clouds generated by different methods.
- Our comparison includes classic radar detectors, OS-CFAR, as well as two depth completion methods that generate pseudo point clouds through back projection.

Methods	Input Pattern	$S_{recall}\uparrow$	$S_{clutter}\downarrow$	$D_H\downarrow$	$D_C\downarrow$
OS-CFAR [32]	Radar	4.190	0.303	8.727	3.823
FusionNet [28]	Camera + Radar	0.126	0.313	7.306	0.840
Sparse to dense [18]	Camera + Radar	0.143	0.248	7.306	0.921
ours	Camera + Radar	1.388	**0.052**	**2.960**	2.365

Summary/Conclusion

- To the best of our knowledge, our research is the first to concentrate on enhancing the quality of point clouds through the camera-radar fusion method. This is a fundamental issue that has not been extensively explored when using millimeter-wave radar for autonomous driving.
- We introduce a novel method that fuses camera and millimeter-wave data to generate high-quality millimeter-wave radar point clouds for autonomous driving's environmental perception tasks.
- We developed a platform and demonstrated the effectiveness of our approach through real-world scenario-based experiments.