FPGA Frontend for Highly Efficient Automotive LIDAR Perception

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***Abstract*— This paper briefly presents the recent progress on automotive perception and the corresponding hardware implementation for the emerging application of autonomous driving systems. The requirements for an automotive road perception algorithm are presented. An FPGA based design for creating custom implementation of road perception are discussed to form an efficient hardware platform for real-time purpose. A special attention is given to determining the efficiency of hardware implementation in terms of speed and power consumption. Finally, the technical challenges are presented to motivate future research and development in this field.**

Keywords- Automotive driving; Field Programmable Gate Array (FPGA); Light Detection and Ranging (LIDAR); Road perception; Artificial Intelligence (AI)

I. INTRODUCTION

The last decade has witnessed tremendous development of autonomous vehicles. These autonomous systems present a great potential for improving safety, increasing productivity, and minimizing their impact on the environment [1]-[3].

Light Detecting and Ranging (LIDAR) system plays an important role in autonomous vehicle systems and recognized as key enabling technology for Advanced Driver-Assisted Systems (ADAS) and autonomous driving, as they enable 3D mapping of objects. Regularly, more than one LIDAR sensors are installed on vehicle for the sense modality of perception, mapping, and localization. One major challenge for LIDAR system is real-time perception.

The core competencies of an autonomous vehicle system are classified into three categories: perception, planning, and control. Figure 1 presents the interactions between these competencies and the vehicles interactions with the environment. Perception refers to the ability of an autonomous system to collect information and extract relevant knowledge from the surrounding environment. The real world is a complex place for partial or even full autonomy, and the lack of predictability and structure poses serious challenges to the deployment of self-driving vehicles. The autonomous system needs to sense the environment, to determine the exact position on the road, and to decide how it should behave in each situation. That is why self-driving cars are highly dependent on software to bridge the gap between sensor physics and the mechanical actuation of the vehicle, e.g., steering and brakes.

Due to the complexity of perception, there are highly challenging requirements and constraints in terms of real-time determines. Besides, there are limitations on hardware properties, such as size and power consumption. For autonomous vehicles, both real-time processing and low power consumption are desirable.

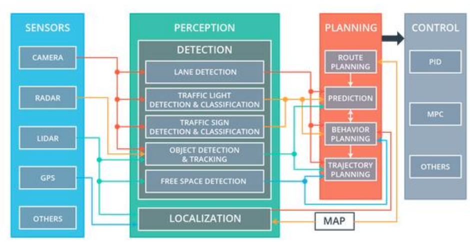

Fig. 1 A vehicle system overview, highlighting core competencies.

Software implementations of LIDAR perception for embedded applications, cannot satisfy the above constraints. Consequently, research has focused on the design of custom hardware architectures for object detection. [4]-[6] Reconfigurable hardware platforms, such as Field Programable Gate Array (FPGA), have emerged as a very attractive platform for implementing architectures for LIDAR perception applications. FPGAs offer high flexibility with regards to area, power, and performance. They can meet application-specific constraints, which is difficult to achieve with other platforms such as CPUs and GPUs due to fixed interconnect and high-power demands of FPGAs.

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II. METHODOLOGY

Graphics-Processing Unit (GPU) systems have been popular for parallel processing method and implementation of road perception algorithms, but still struggle to comply with the space and power limitations of vehicles. Conversely, a mobile/embedded CPU/GPU system, simply lacks the computing power required for computational processing.

An FPGA can be developed as customized integrated circuit, which is able to perform massive parallel processing and data analysis on a chip. FPGAs emerged in image processing and Deep Learning (DL) due to their incredible benefits of faster mathematical computations, and processing operations. Additionally, capability of recent frameworks allowed to import the work more straightforwardly into an FPGA.

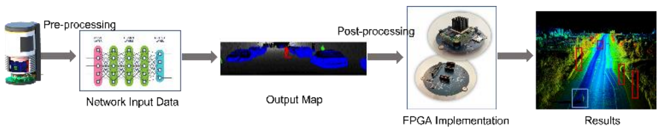

Fig. 2 FPGA implementation of LIDAR perception.

The methodology to implement the FPGA front-end for LIDAR perception consists of the LIDAR data as an input, an intelligent algorithm as a processing tool and top-view predictions as the main output to evaluate the road perception (Figure 2). The algorithm has four steps to process the LIDAR data including:

1. Pre-processing which arranged the input data and created the tensors that can flow through the layers for processing phase.
2. Neural-network processing which do the adaptation of Neural Network (NN) algorithm for perception to improve computational efficiency and suitability for hardware implementation.
3. Evaluation of multiple types of Neural Network in the context of hardware and computational energy efficiency.
4. Development, implementation and testing of reconfigurable hardware architectures exploiting parallelism to increase speed and reduce memory requirements.

Additionally, limited computational resource in an embedded system, raise the need of efficient compression method. To aim this goal, in this paper the new compression algorithm has been design and implemented to compress the point-cloud data and minimize the FPGA memory in post processing. Results obtained from neural network are projected back to targeted views for performance validation. Figure 3 presents the FPGA implementation of compression algorithm for LIDAR point-cloud.

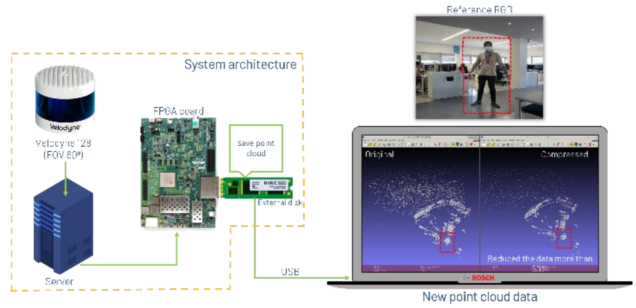

Fig. 3 Compression algorithm implementation for LIDAR point-cloud.

III. RESULTS AND FUTURE WORKS

The experimental results indicated that the proposed hardware architecture implemented on FPGA, could process each LIDAR scan in 15-18 millisecond, which is significantly faster than convenient hardware implementation and pervious works.

All convolution layers have been taken several milliseconds to complete due to FPGA parallelization. Since LIDAR normally scans at 10HZ, this FPGA implementation fulfils the requirements of the real-time processing. The results of compression algorithm showed significant compress rate of point-cloud data, resulting in speed of entire post-processing stages.

Conclusively, this work introduces the framework for implementation of highly complex pipelines, such as deep learning approach that has the potential to speed-up LIDAR perception processing. Evaluations showed that the proposed LIDAR processing algorithm could achieve state-of-art performance in accuracy and real-time processing. Such a system will have far better real-time determinism than a software-based approach, while providing sufficient computational complexity for object detection and road perception.

Regardless of all progresses in hardware implementation of LiDAR perception, the FPGA implementation still consumes a large amount of on-chip memory. This is the reason that for future work, the Spike Neural Network (SNN) can be considered as a solution to reduce the on-chip memory usage.

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REFERENCES

[1] J. Levinson et al., *Towards fully autonomous driving: Systems and algorithms*, IEEE Intelligent Vehicles Symposium, Proceedings, 2011.
[2] R. Zhang, K. Spieser, E. Frazzoli, and M. Pavone, *Models, algorithms, and evaluation for autonomous mobility-on-demand systems*, in Proceedings of the American Control Conference, 2015.
[3] S. D. Pendleton et al., *Perception, planning, control, and coordination for autonomous vehicles*, Machines, 2017.
[4] Y. Lyu, L. Bai, and X. Huang, *Real-Time Road Segmentation Using LiDAR Data Processing on an FPGA*, in Proceedings - IEEE International Symposium on Circuits and Systems, 2018.
[5] J. P. Mitchell, C. D. Schuman, and T. E. Potok, *A small, low-cost event-driven architecture for spiking neural networks on FPGAs*, International Conference on Neuromorphic Systems 2020, 2020, pp. 1–4.

[6] y. lyu, l. bai, and x. huang, *chipnet: real-time lidar processing for drivable region segmentation on an FPGA*, IEEE trans. circuits syst. i, vol. 66, no. 5, pp. 1769–1779, May 2019.