Solution

# Lidar 3D Point Cloud Processing and Sensor Fusion based on Intel® Architecture for C-V2X


## Abstract

In the applications of Cellular Vehicle-to-Everything (C-V2X), the traffic object and traffic environment information obtained by the Roadside Sensing Equipment is analyzed by the Roadside Edge Computing Equipment to generate various Infrastructure-to-Vehicle (I2V) messages which are sent by the Roadside Unit (RSU) to various Road Traffic Participants (including networked vehicles and vulnerable road users) through the wireless links to improve the traffic safety and efficiency. Lidar, as a Roadside Sensing Equipment, is being used more and more widely due to its excellent performance such as 3D imaging and precise ranging. The Roadside Edge Computing Equipment based on **Intel® Architecture** have shown superior performance in processing the 3D point cloud generated by lidar (whether it is deep learning or traditional computer vision). This paper introduces the **JHCTech® Roadside MEC Equipment** based on the **11th-Generation Intel® Core™ Processors** and **Intel® Distribution of OpenVINO™ Toolkit**, which is used to support the 3D point cloud processing based on deep learning and the Sensor Fusion for **Leishen® All-in-One Roadside Sensing Equipment** (Lidar and Camera). We provide cost-effective Roadside Sensing and Roadside Edge Computing solutions for the C-V2X industry.



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## Background: Rapid Development of China's Intelligent Transportation Infrastructure

In recent years, China has unveiled a number of industrial policies to support the development of Intelligent Transportation System (ITS), such as the "Guidelines on Developing Comprehensive National Transport Network", which emphasizes that the comprehensive deployment of traffic sensing systems is an important step in achieving intelligent transportation infrastructure.

As a new type of industry that integrates technologies such as automotive, semiconductor, wireless communications and transportation, the C-V2X has the great potential to improve the traffic safety and efficiency. With the rapid development of technologies such as artificial intelligence, edge computing and mobile networking, the functions and performance of the C-V2X are constantly being improved, and it will play an important role in the future ITS. China attaches great importance to the development of the C-V2X industry and has successively issued a series of policy documents such as the "Internet of Vehicles (Intelligent Connected Vehicles) Industry Development Action Plan" and "Intelligent Vehicle Innovation and Development Strategy". The Chinese industry has been actively promoting the Vehicle-Infrastructure Collaboration technical route built around the C-V2X technology.

The Roadside Infrastructure is an important part of the C-V2X industry. Its technologies and standards are continuously being improved, and the formation of related industry chains (including Roadside Sensing, Roadside Edge Computing and Roadside Communication, etc.) is also accelerating. The C-V2X Working Group under China's IMT-2020 (5G) Promotion Group has released a research report "Roadside Sensor Fusion based on Edge Computing" which systematically introduces the status quo of the technology and industry development [1].

As the world's leading chip manufacturer, Intel is also accelerating the research and development of related products and solutions with Chinese partners including Leishen and JHCTech to promote the commercialization of the Vehicle-Infrastructure Collaboration based on C-V2X.

## Roadside Sensing and Roadside Edge Computing in C-V2X

As shown in Figure 1, C-V2X relies on the Roadside Sensing Equipment (including cameras, lidars and mmWave radars, etc.) to collect the raw information of the traffic objects (including 2D video images and 3D point clouds, etc.), and then pass them to the Roadside Edge Computing Equipment for analysis (including object detection and object classification) and sensor fusion to generate the structured data representing the attributes of traffic objects (such as vehicle speed and heading, traffic event category and impact scope, etc.). These structured data are further processed into V2X messages, to be precise, the I2V messages. These I2V messages are sent to the road traffic participants including motor vehicles and pedestrians by the RSU via the PC5 air interface (sidelink) or the 5G/4G base station (gNB/eNB) via the Uu air interface (cellular link).

The roadside infrastructure of the C-V2X is shown in Figure 2. It can be divided into Roadside Sensing (e.g., various types of traffic sensors including cameras, lidars and mmWave radars), Roadside Edge Computing (e.g., Roadside MEC) and Roadside Communications (e.g., RSU). We mainly focus on the two parts of Roadside Sensing and Roadside Edge Computing in this paper.

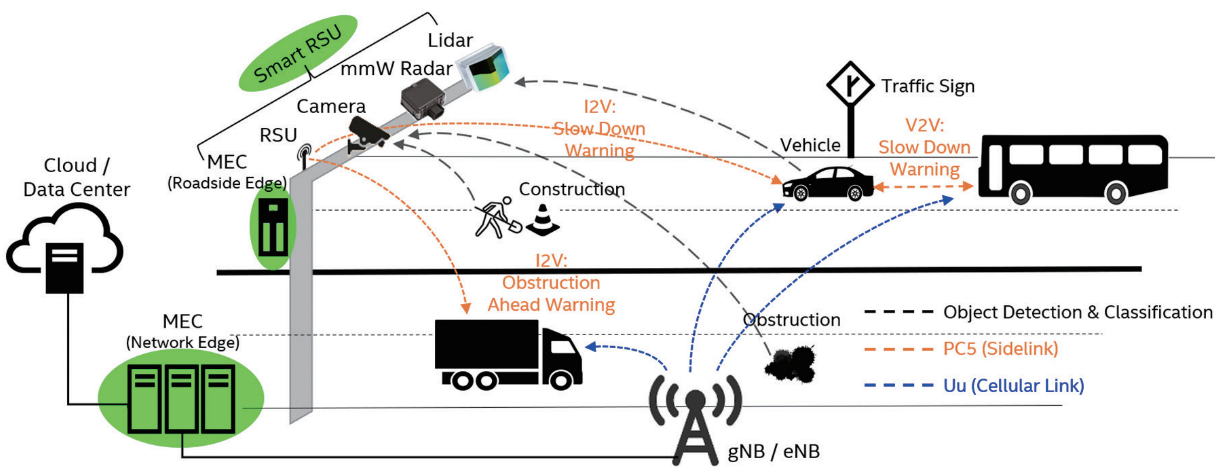


**Figure. 1.** System concept of Vehicle-Infrastructure Collaboration based on C-V2X.

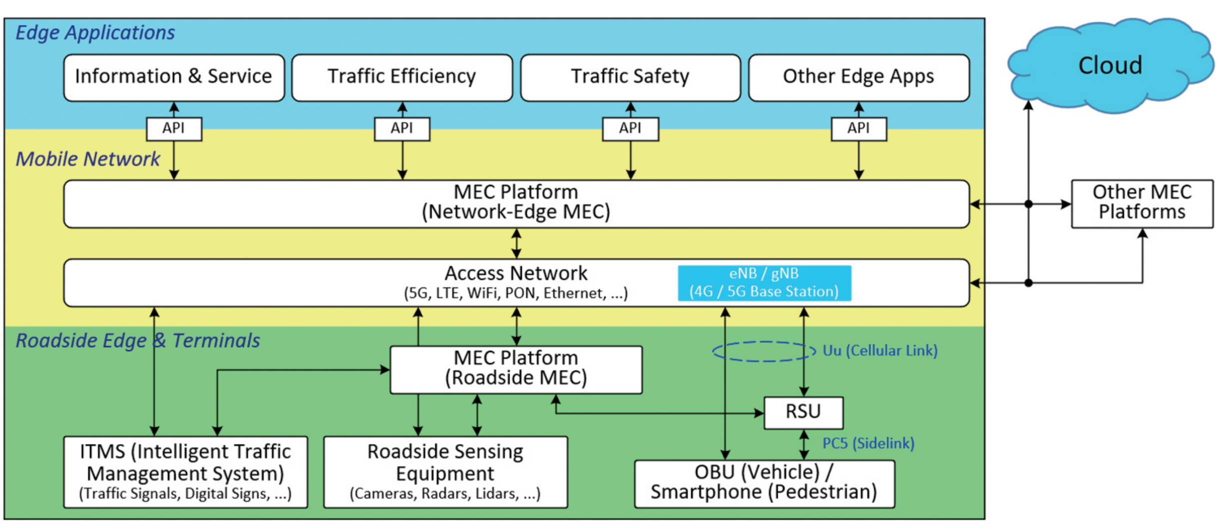


**Figure. 2.** Roadside infrastructure of C-V2X.

## Roadside Sensing

In the area of Roadside Sensing, the commonly used traffic sensors include cameras, lidars and mmWave radars. The technical solutions introduced in this paper involve the first two, and we will introduce their respective technical features below.

### Camera

The camera is the most common roadside traffic sensor. Based on the analysis of the images and videos it collects, we can obtain rich color, texture and semantic information to achieve refined classification of traffic objects. However, its limitations are also prominent, mainly reflected in the fact that it is greatly affected by the light or bad weather conditions, and it is difficult to reliably recognize traffic objects. The advantages and disadvantages of the camera as a traffic sensor are summarized in Table 1.

### Sensor Fusion: Lidar and Camera

The Sensor Fusion refers to the cooperation of two or more sensors to complete the detection and classification of objects. Due to the performance of "learning from each other's strengths", the Sensor Fusion has more comprehensive sensing capabilities and better performance than a single sensor. The Sensor Fusion based on the combination of lidar and camera can not only take advantage of the precise ranging capability of lidar, but also rely on the camera to recognize the traffic object's colors, traffic signs, and traffic signals. In other words, the Sensor Fusion can be achieved through the "division of labor" between the camera and the lidar, where the camera is used for the object classification and the lidar is used for the object detection. In this case, the 3D point cloud processing can use the non-deep learning methods such as the Point Cloud Library (PCL) [2][3], thereby reducing the overall complexity of the algorithm and the corresponding hardware cost. This makes the cost-effective solutions possible.

### Lidar

Lidar is becoming an increasingly important sensor in the intelligent transportation. It actively emits a laser beam into the target spatial area, and receives the reflected signal and compares it with the emitted signal to generate the 3D point cloud. After further processing, the accurate information such as the distance, angle, speed, 3D size and classification of the traffic object can be obtained.

Lidar can be divided into the following large and small categories according to the working principle of its internal laser scanning mechanism:

- Mechanical
  - Integral rotation
  - Prism rotation
- Non-mechanical
  - Hybrid solid-state
    - Mainly based on the micro-electromechanical system (MEMS) mirror
  - Solid-state
    - Flash
    - Optical phased array (OPA)

The advantages and disadvantages of lidar as a traffic sensor are summarized in Table 1.

**Table 1.** Comparison of the advantages and disadvantages of camera and lidar.

| Sensor | Advantages | Disadvantages |
|---|---|---|
| **Camera** | ▪ Rich in details, excellent discernibility;<br>▪ Can accurately capture the information such as the contour, texture, color distribution, etc., which facilitates object classification / recognition under non-extreme ambient light conditions;<br>▪ Can recognize stationary or flat traffic objects (such as traffic signs and lane lines);<br>▪ High lateral resolution, which can be used to estimate lateral velocity;<br>▪ Video and image processing technologies are relatively mature. | ▪ Susceptible to ambient light conditions (e.g., low light at night, strong light, etc.);<br>▪ Susceptible to weather conditions (e.g., rain, snow, fog, haze, smoke, dust, etc.);<br>▪ Relatively high workload of video analytics based on DL;<br>▪ Lack of depth information, difficult to obtain accurate 3D information;<br>▪ Low positioning accuracy;<br>▪ Difficult to estimate radial velocity. |
| **Lidar** | ▪ High ranging resolution and precision;<br>▪ High angular resolution;<br>▪ Wide FoV;<br>▪ Strong recognition ability: capable of 3D imaging, identify target 3D (such as length, width, height) and other information, and obtain accurate contours of pedestrians and even smaller objects;<br>▪ Accurate positioning of multiple targets;<br>▪ Strong tracking ability;<br>▪ Not affected by ambient light conditions. | ▪ Limited performance in recognizing information such as target colors, traffic signs, and traffic signals;<br>▪ DL inference on the 3D point cloud generated by lidar requires relatively high computing power. |

## Roadside Edge Computing: Promoting the Sensor Fusion in C-V2X applications

The Roadside MEC Equipment based on **Intel® Architecture** can perform the inference based on deep learning or analysis based on traditional computer vision on the 2D video images and 3D point clouds, respectively, and merge the results of the two by Sensor Fusion algorithms.

### System Architecture

In the applications of C-V2X, the Multi-access Edge Computing (MEC) plays an extremely important role. According to the deployment location and the specific requirements for latency and computing power, the MEC can take many forms, including the Roadside MEC and the Network-Edge MEC (as shown in Figure 2). The various MEC equipment based on Intel® Architecture [4][5] provide powerful and reliable general-purpose and AI computing power for various use cases of C-V2X. This enables us to perform real-time and efficient analysis of information from different types of traffic sensors and fuse the results, which significantly improves the safety and efficiency of the ITS.

The C-V2X applications for traffic safety have strict requirements for end-to-end (E2E) latency. The Roadside MEC deployed near the Roadside Sensing Equipment and Roadside Communication Equipment (RSU) have a better guarantee for reducing the E2E latency.

### 11th-Gen Intel® Core™ Processors (Tiger Lake)

For many vertical industry applications including C-V2X, Intel released the 11th-Gen Intel® Core™ Processors (Tiger Lake), which have powerful general-purpose computing and AI acceleration computing capabilities, low power consumption and easy heat dissipation design. It is an ideal computing platform with high cost performance and high energy efficiency for the Roadside Edge Computing Equipment. Many SKUs (models) in this series of processors also support the extended temperature and the Intel® vPro® platform technology for the remote management and maintenance of the computing equipment.

The performance evaluation in this paper is based on the following two processors, the configuration of which is shown in Table 2.

- Intel® Core™ i7-1185GRE
- Intel® Core™ i7-1165G7

The maximum performance of the two processors is detailed in the product technical specifications [6][7].

**Table 2.** Configurations of the 11th-Gen Intel® Core™ processors (Tiger Lake)

| Processor SKU | Intel® Core™ i7-1165G7 | Intel® Core™ i7-1185GRE |
|---|---|---|
| CPU | 4 cores, 8 threads<br>Configurable TDP-up Freq.: 2.80 GHz | 4 cores, 8 threads<br>Configurable TDP-up Freq.: 2.80 GHz |
| Processor Graphics (iGPU) | Intel® Iris® Xe Graphics<br>96 EUs<br>Graphics Max Dynamic Freq.: 1.30 GHz | Intel® Iris® Xe Graphics<br>96 EUs<br>Graphics Max Dynamic Freq.: 1.35GHz |
| AI Performance (FP32) | 1.996 TFLOPS (iGPU)<br>0.358 TFLOPS (CPU) | 2.073 TFLOPS (iGPU)<br>0.358 TFLOPS (CPU) |
| AI Performance (INT8) | 7.987 TOPS (iGPU)<br>1.433 TOPS (CPU) | 8.294 TOPS (iGPU)<br>1.433 TOPS (CPU) |
| Memory | 8 GB, DDR4, Speed: 2400 MT/s | 8 GB, LPDDR4, speed: 4267 MT/s |
| BIOS | American Megatrends Inc.<br>2.21.1278 | Intel Corporation<br>TGLSFWI1.R00.4024.A01.2101201730 |

## JHCTech® Roadside MEC Equipment

Based on the above two 11th-Gen Intel® Core™ Processors, JHCTech has developed a brand new KMDA-3301 Roadside MEC Equipment (as shown in Figure 3). Its main features include: fanless heat dissipation, rich I/O interfaces, aluminum material, slim body, shock absorption design, etc.. This equipment is very suitable for the deployment in harsh environments such as the roadside, and can provide reliable high computing power for C-V2X applications. For detailed product specifications, please refer to the website [8].

**Figure. 3.** JHCTech® Roadside MEC Equipment (KMDA-3301).

## Intel® Distribution of OpenVINO™ Toolkit

The Intel® Distribution of OpenVINO™ Toolkit (hereinafter referred to as OpenVINO™) is a very comprehensive and excellent software toolkit from Intel, which is used to accelerate the development of rich and diverse applications of high-performance computer vision and deep learning [9][10]. Its three prominent features are: high-performance deep learning inference; very easy-to-use simplified development process; programs written once can be deployed flexibly.

Specifically, OpenVINO™ supports the rapid development of rich and diverse applications and solutions to simulate human vision. It can significantly improve the accuracy of video analytics, speed up inference, and save computing resources. This toolkit is based on the Convolutional Neural Network (CNN), supports direct heterogeneous execution, and can expand the workload of computer vision and deep learning on a variety of Intel® processor platforms to achieve superior performance. The Intel® Media SDK in the toolkit supports high-performance video encoding and decoding on Intel® Processor Graphics (i.e., iGPU: integrated GPU). OpenVINO™ supports multiple operating systems (including Windows, Linux and macOS) and programming languages (including Python and C++).

OpenVINO™ provides more than 280 pre-trained neural network models and reference codes for free, supports quantization and tuning of models, and accelerates inference based on deep learning.

### Operating System and Software Configuration

The operating system and software involved in the performance evaluation use the configuration listed in Table 3.

**Table 3.** Operating system and software configuration.

| | |
|---|---|
| **Operating System** | Ubuntu 20.04.1 LTS |
| **Linux Kernel** | 5.8.0-43-generic |
| **PyTorch** | 1.7.1+CPU |
| **OpenVINO** | 2021.3 |

## 3D Point Cloud Processing based on Intel® Architecture

As a Roadside Sensing Equipment in C-V2X, lidar can be used as an independent sensor, or it can be used with a camera to form a solution for Sensing Fusion. The computing power required for information processing in these two solutions is carried by the Intel® processors in the MEC equipment. We respectively introduce the technical challenges that these two solutions need to solve, the solutions based on Intel® Architecture, and the performance evaluation results.

### Lidar as a standalone traffic sensor

#### Solution based on Intel® Architecture

In this solution, the detection of traffic objects is based on the deep learning inference of 3D point cloud generated by lidar, which requires very high computing power. In actual traffic applications, the throughput (i.e., processing speed) needs to reach at least 10 frames per second (FPS). Improving the throughput by optimizing the 3D point cloud processing pipeline based on deep learning [11][12] is crucial for improving the cost performance and energy efficiency of the MEC platform deployed on the roadside.

We use OpenVINO™ to optimize the PointPillars [12], an open source 3D point cloud deep learning model. As shown in Figure 4, the blue module are still implemented using the native codes in Python, while the green modules are accelerated using the Model Optimizer (MO) in OpenVINO™. For details, please see [13][14].

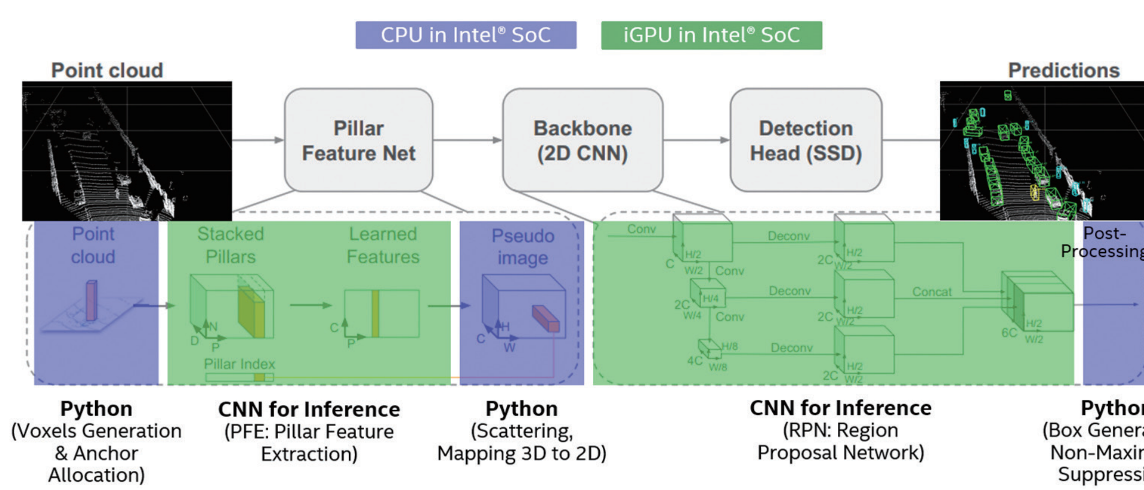


**Figure. 4.** PointPillars model implemented on Intel® Core™ processors (Tiger Lake).

### Performance Evaluation

We used the training set in the KITTI dataset [15] to evaluate the performance. Compared with the PyTorch models before the OpenVINO™ optimization, the models of intermediate representation (IR) format after OpenVINO™ optimization can significantly improve the throughput and latency performance (as shown in Table 4). According to the actual needs, we can further increase the throughput and reduce the latency by adjusting the parameters of the PointPillars model.

**Table 4.** Throughput and latency (3D point cloud processing based on deep learning).

| Processor SKU | Intel® Core™ i7-1165G7 | Intel® Core™ i7-1185GRE |
|---|---|---|
| Neural Network Models (Precision) | PFE (FP16), RPN (INT8) | PFE (FP16), RPN (INT8) |
| Throughput (FPS) | 10 | 11.1 |
| Latency (ms) | 165.8 | 154.7 |
| iGPU Loading Rate [1] | 85% | 86% |
| CPU Loading Rate [2] | 430% | 430% |

[1] iGPU loading rate can be checked by "intel_gpu_top" command in Linux, the maximum value is 100%;

[2] CPU loading rate can be checked by "top" command in Linux, the maximum value is 800% (4 cores, 8 threads).

## Sensor Fusion: Lidar and Camera

### Leishen® All-in-One Roadside Sensing Equipment

The Leishen® All-in-One Roadside Sensing Equipment and its deployment scenarios are shown in Figure 5. It uses a camera and a Leishen® CH128X1 lidar to obtain the raw data of traffic objects and environment, and pass it to the JHCTech® Roadside MEC Equipment which is based on the 11th-Gen Intel® Core™ Processor through the Ethernet.


**Figure. 5.** Leishen® All-in-One Roadside Sensing Equipment (Lidar & Camera).

The Leishen® CH128X1 lidar scans the space through the rotation of its prism to realize the scanning of the horizontal 120° area. Its specifications are shown in Table 5 below.

**Table 5.** Specifications of Leishen® CH128X1 lidar.

| | | |
|---|---|---|
| Ranging Method | | ToF (Pulsed Lidar) |
| Laser Wavelength | | 905 nm |
| Number of Lines (Laser Beams) | | 128 |
| Maximum Range | | 160m @ 10% (Reflectivity) |
| Range Resolution | | ±3 cm |
| Data Rate (Single Echo) | | 760,000 points/sec |
| Field of View (FoV) | Vertical | -18°–7° |
| | Horizontal | 120° |
| Angle Resolution | Vertical | 0.125° (Central ROI Region)<br>0.25° (Side Regions) |
| | Horizontal | 0.1° (5 Hz)<br>0.2° (10 Hz)<br>0.4° (20 Hz) |

## Solution based on Intel® Architecture

In order to take into account both the throughput and accuracy performance, Leishen and Intel jointly proposed an Object-Level Sensor Fusion scheme which is based on the combination of the traditional algorithms and deep learning. The processing pipeline is shown in Figure 6. For the 3D point clouds generated by lidar, we use the clustering and tracking algorithms in PCL [2][3] to obtain the information such as the position, distance and speed of the traffic object; for the 2D images generated by the camera, we use the deep learning based on the Yolo-v5 neural network and OpenVINO™ to recognize the category of the traffic object.

We project the center point of the object obtained by the clustering of the 3D point cloud onto the 2D image, and evaluate whether the distance between this point and the position center of the object detected by the deep learning inference of the 2D image is less than a certain threshold: if so, we determine that the objects detected by lidar and camera respectively are the same one, and the object-level results obtained by the two sensors are fused. As shown in Figure 6, the fusion results include the object's category, distance and speed. These results can be displayed in the 2D image or the 3D point cloud as needed.

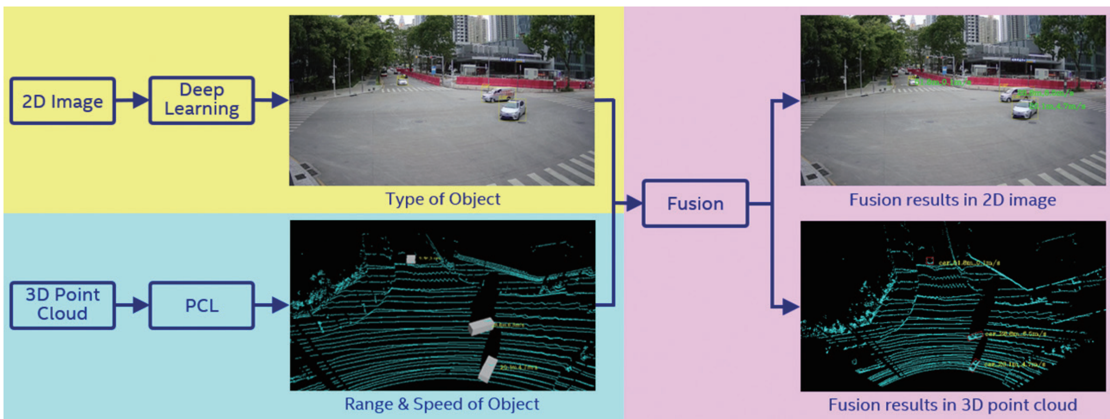


**Figure. 6.** Object-level sensor fusion of lidar and camera.

## Performance Evaluation

We used the 3D point cloud dataset collected from the Leishen® CH128X1 lidar. The data file contains multiple frames of point cloud. The parameters of each point include its 3D coordinates (x, y, z) and reflectivity (r). After the point cloud is processed, a 3D bounding box around the detected object is generated.

The label of the detection results is in a format similar to that used in the KITTI dataset. We used JHCTech® Roadside MEC Equipment (KMDA-3301) [8] and OpenVINO™ [9][10] to evaluate the proposed Object-Level Sensor Fusion scheme, and its performance is shown in Table 6.

**Table 6.** Evaluation results of Sensor Fusion scheme.

| Scheme | Workload | Computing Platform | Latency / Frame (ms) | FPS | iGPU Loading Rate | CPU Loading Rate |
|---|---|---|---|---|---|---|
| 1 | DL for Image | CPU | 71.09 | 14.1 | 2% | 334% |
| 2 (Sensor Fusion) | DL for Image | CPU | 73.16 | 13.7 | 6% | 348% |
| | PCL for Point Cloud | CPU | | | | |
| 3 | DL for Image | iGPU | 49.79 | 20.1 | 52% | 114% |
| 4 (Sensor Fusion) | DL for Image | iGPU | 55.87 | 17.9 | 56% | 203% |
| | PCL for Point Cloud | CPU | | | | |

(DL: Deep Learning)

The evaluation results show that whether the lidar is used as an independent sensor or combined with a camera to form a Sensor Fusion scheme, the lidar 3D point cloud processing based on the Intel® Architecture can achieve excellent performance.

## Outlook

5G has been commercialized on a large scale in China, laying the foundation for the interconnection of terminal devices with a high-speed, low-latency and extensively connected network. As one of the most eye-catching application scenarios in 5G vertical industries, the C-V2X will also accelerate its development. The standardization of the C-V2X based on the 5G new radio (NR) air interface has been completed in June 2020, and large-scale trials are about to start. The lidar 3D point cloud processing and Sensor Fusion based on Intel® Architecture actively empowers the C-V2X industry, enabling a variety of ITS applications to significantly improve the traffic safety and efficiency.

The data-centric Intel Corporation uses the world's leading end-to-end AI and computer vision technologies and cooperates with the industry partners to lay a solid foundation for the rapid development of the global C-V2X / ITS industry.

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## About Intel

Intel (NASDAQ: INTC), as an industry leader, creates technologies that change the world, promotes global progress and enriches life. Inspired by Moore's Law, we are continuously committed to advancing semiconductor design and manufacturing to help our customers meet the most significant challenges. By integrating intelligence into the cloud, network, edge, and various computing devices, we unleash the potential of data and help businesses and society become better. For more information on Intel's innovation, please visit Intel China News Center (https://newsroom.intel.cn) and the official website (https://www.intel.cn).

## About Leishen

Leishen has achieved multiple milestones in the industry: it is the only lidar manufacturer in the world that has mastered the four measurement principles of ToF, phase, triangulation and FMCW, creating the most complete lidar product portfolio; it is the only lidar manufacturer in China that has developed the 16-channel TIA chip, 1550nm fiber lasers and automatic lidar production lines. Leishen is one of the first companies to develop the hybrid solid-state lidar with rotating prism, and has successfully developed China's first and the world's second automotive-grade lidar: CH32. Leishen's industry-leading CH128X lidar is based on the miniaturization technology of the high-beam and hybrid solid-state lidar. It has not only the excellent performance of long range, wide FoV and high resolution, but also the greatly reduced physical size. Leishen is well recognized as the leading lidar manufacturer in the industry.

Official websites: http://www.leishen-lidar.com/ (Chinese), http://www.lslidar.com/ (English).

## About JHCTech

JHCTech was established in Shenzhen, China, in April 2002, and it has become an intelligent IoT system supplier with strong capabilities in R&D, production, sales and service. Relying on its rich industry experiences and following the strategy of "Proactive Innovation and Intelligent Manufacturing Based in China", JHCTech has been focusing on the development and production of industrial computers and system application platforms. Its diversified products and services include the industrial tablet computers, industrial touch monitors, embedded box computers, single-board computers, etc., as well as customized solutions focusing on industry applications and AI-enabled value-added services. Its products have passed the CE, FCC, E-Mark, EN50155 and other safety regulations and industry certifications, and are widely used in many areas including the Industrial Internet of Things (IIoT), Intelligent Transportation System (ITS), Smart Security, Energy, Environmental Protection and Biological Safety. JHCTech has built a solid foundation in the Intelligent IoT and Edge Computing.

Official websites: http://www.jhctech.com.cn/ (Chinese), http://www.jhctechnology.cn/ (English).