Chapter 1

INTRODUCTION

Autonomous vehicles will fundamentally improve the safety and comfort of the driving population while reducing the environmental impact of automobiles. To develop such a vehicle, the perceptual system is an indispensable component that will enable the vehicle to perceive the driving environment, including the position, orientation and classification of the surrounding obstructions. Therefore, sensors such as light detection and ranging (LIDAR), cameras, radar and sonar have been widely applied in the environment sensing systems of autonomous vehicles.

LIDAR is one of the most popular sensors used in autonomous-vehicle perceptual systems. These sensors have a wide range of view with precise depth information and long-range and night-vision capabilities in target recognition. In object detection tasks, LIDAR has certain advantages over cameras in acquiring the posture and shape of the detected objects, since, by definition, laser scans contain the spatial coordinates of the point clouds. However, the distribution of LIDAR point clouds becomes increasingly sparse with increasing distance from the scanning centre, which makes it difficult for a LIDAR to detect specific objects in the classification step.

Cameras can provide high resolution images for precise classification, and the classification methods widely used in recent years have been based on extensive deep learning research in the field of image recognition. To obtain highly accurate object locations and classifications in driving environments, one possible approach is to take full advantage of the complementary information provided by LIDAR and cameras.

Chapter 2

SENSOR FUSION

Sensor fusion is the process of collectively taking inputs from RADAR, LiDAR, camera, and ultrasonic sensors to interpret environmental conditions for detection certainty. It's not possible for each sensor to work independently and deliver all the information needed for an autonomous vehicle to operate with the highest degree of safety.

Using multiple types of sensors together allows autonomous driving systems to experience the benefits of sensors collectively while offsetting their individual weaknesses. Autonomous vehicles process sensor fusion data dependent on algorithms programmed. This allows self-driving vehicles to form judgements to take the right action.

2.1 Sensor fusion levels and architectures

Sensor fusion is the process of combining inputs from two or more sensors to produce a more complete, accurate, and dependable picture of the environment, especially in dynamic settings. The goal of sensor fusion is to provide those improved results with the minimum number of sensors and minimum system complexity for the lowest cost.

At the most basic level, sensor fusion is categorized as centralized or decentralized by the type of data being used, raw data from sensors, features extracted from sensor data, and decisions made using the extracted features and other information

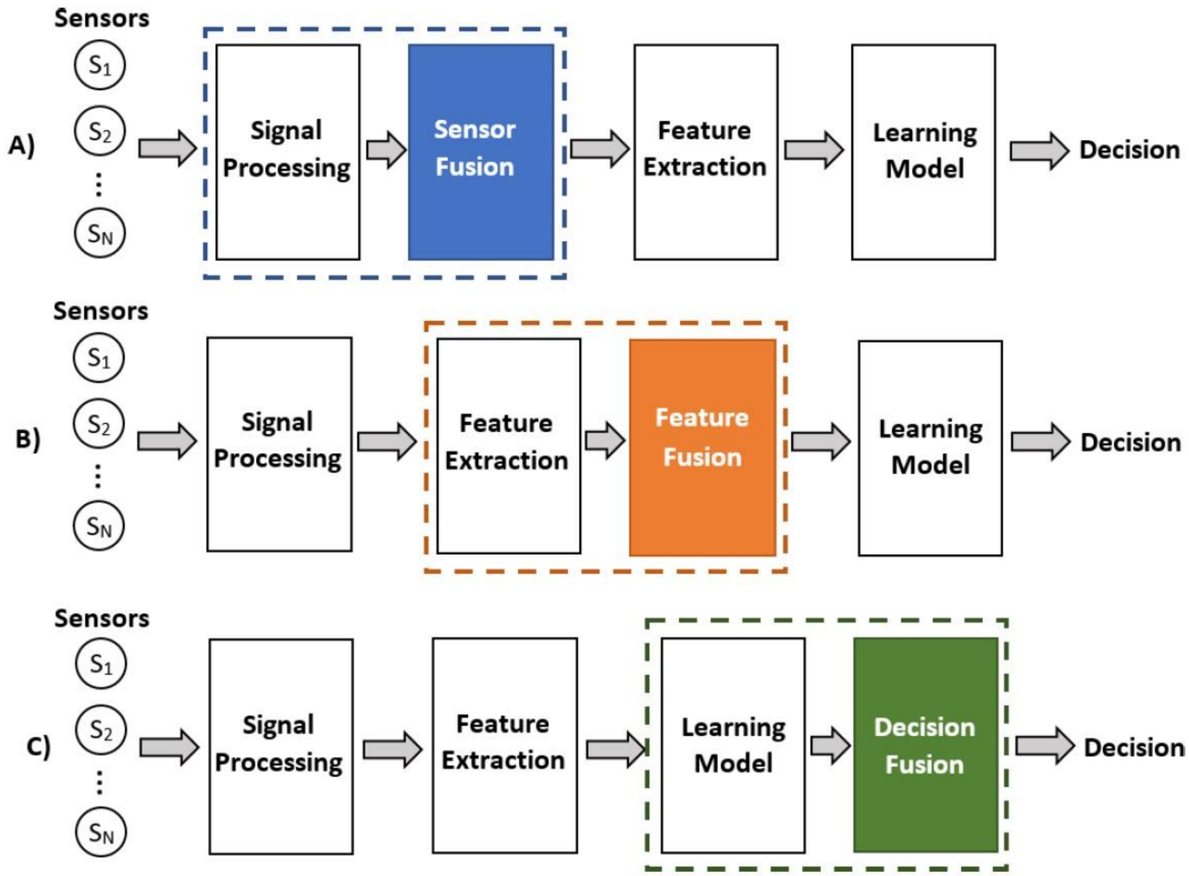


Fig 2.1.1 Sensor fusion levels and architectures

Sensor fusion typically includes three levels of abstractions:

- Sensor-level abstraction processes the raw sensor data. If multiple sensors are used to measure the same physical attribute, the data can be combined at this level. For sensors measuring different attributes, the data is combined at a higher level.
- Feature level abstraction extracts features from various independent sensors to produce individual feature vector representations.
- Decision level abstraction classifies the various features and uses the resulting data to make decisions about the environment and identify any necessary actions that need to be carried out.

2.2 Classifications of sensor fusion

Various ways to classify this technology:

Data origination

- Direct Fusion: The fusion of sensor data from heterogeneous or homogeneou sensors.
- Indirect Fusion: The fusion of data from existing environmental or human sources.

The location of data fusion

- Centralized: Data is sent to a central location where it is fused and processed.
- Decentralized: Data is captured onsite where it is fused and processed.

2.3 Benefits of sensor fusion

- Increased data quality
- Increased data reliability
- Estimation of unmeasured states
- Increased coverage areas
- Shorter response time

Chapter 3

TYPES OF SENSORS USED IN SENSOR FUSION

A sensor is a device that measures physical input from its environment and converts it into data that can be interpreted by either a human or a machine.

3.1 **LiDAR Sensors**

LiDAR sensors use lasers to scan the external environment and distance from objects through the speed of light to generate multiple data points to turn into point clouds. Autonomous driving systems use LiDAR to analyze lane markings or detect road.

Fig 3.1.1 LiDAR Sensor

LiDAR Sensor emits pulsed light wave from the laser into the environment. These Pulses bounce off surrounding objects and return to the Sensor. The sensor uses the time it took for each pulse to return to the sensor to calculate the distance it traveled.

LIDAR APPLICATIONS IN AVS:

- Emergency brake assist (EBA)
- Pedestrian detection
- Collision avoidance System

Advantages

- Long range detection (more than camera)
- Track movement and direction of objects
- High resolution 3D modeling (better than RADAR)
- Unaffected by darkness or bright light conditions

Disadvantages

- Poor visibility in fog, dust, rain, or snow
- Sensitive to dirt/debris
- Bulky in size and moves to function
- Expensive

3.2 RADAR Sensors

RADAR sensors emit electromagnetic (radio) waves to gather more information on objects velocity, range, and angles through the speed of reflected waves returned. This is nothing new for the automotive space; police have been using this in their vehicles to detect and regulate vehicles surpassing the speed limit.

Fig 3.2.1 RADAR Sesor

RADAR APPLICATIONS IN AVS:

- Adaptive cruise control (ACC) (long-range)
- Cross traffic alert (medium-range)
- Blind spot monitor (medium-range)
- Rear collision warning (RCW) (medium-range)

Advantages

- Unaffected by weather conditions
- Unaffected by lighting and noise
- Detects objects at long distances
- Works best for detecting speed of other vehicles
- Inexpensive

Disadvantages

- Limited depth and may falsely identify objects
- Can’t detect small objects and may overlook objects
- Low-definition modeling of objects

3.3 Camera Sensors

Camera sensors capture high resolution images and videos from different angles to obtain visual data of things that can only be “seen” like traffics signs, animals, and road markings.

Fig 3.3.1 Camera Sensor

CAMERA APPLICATIONS IN AVS:

- Lane departure warning (LDW)

- Traffic sign recognition
- Surround view camera

Advantages

- Easily distinguish shapes and color to classify objects
- High degree of environmental sensing
- Recognize 2D information through high-definition images
- Small size for discreet placement
- Inexpensive

Disadvantages

- Poor visibility in harsh weather conditions like snowstorms
- Limited contrast and no depth perception
- Affected by extreme light shifts such as dark shadows or bright lights can obscure object detection
- Don’t provide quantifiable distance information

3.4 Ultrasonic sensors

Ultrasonic sensors emit pulses of sound to detect large and solid objects nearby through the speed of echoes returned. They are used to measure objects that are in proximity such as curbs or other vehicle while parking.

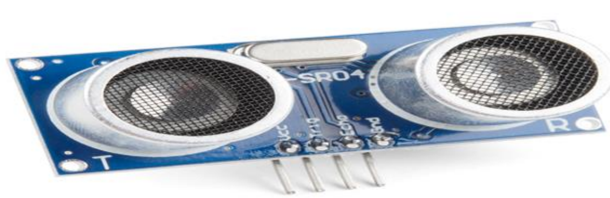


Fig 3.4.1 Ultrasonic Sensor

ULTRASONIC APPLICATIONS IN AVS:

- Intelligent parking assist system

Advantages

- Most accurate for objects in close proximity
- Unaffected by color of objects
- Works well in the dark
- Precise at measuring parallel surface distance
- Compact and inexpensive

Disadvantages

- Can’t detect soft objects well
- Inaccuracy occurs with temperature shifts
- Limited by short range detection

Chapter 4

OBJECT DETECTION SYSTEM

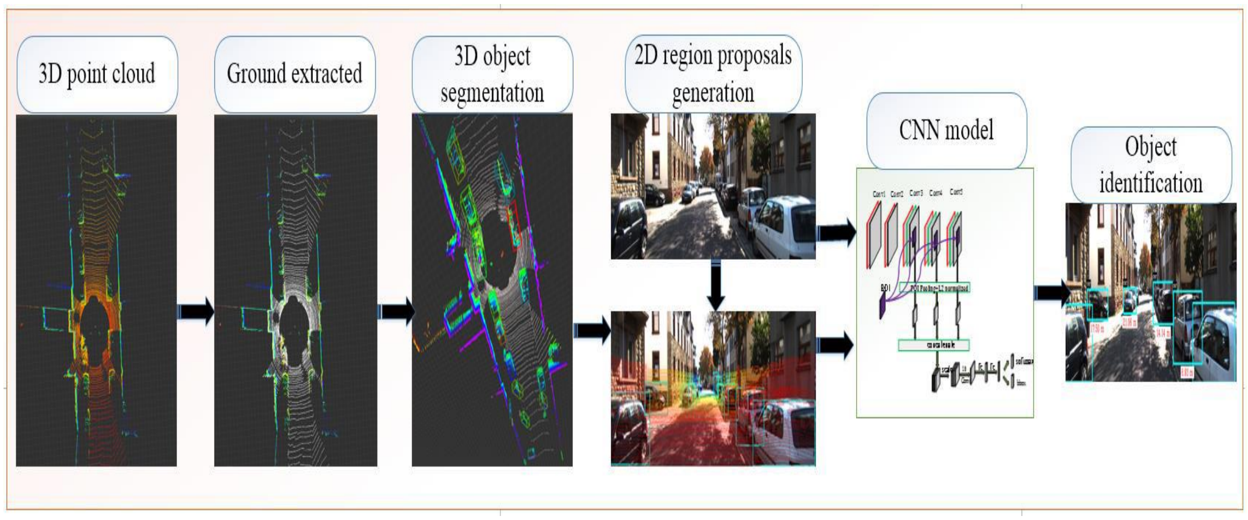


Fig 4.1 Framework of the proposed object detection System

Figure 4.1 shows the framework of the proposed object detection algorithm. This approach has two input modalities, including the point cloud captured by a LIDAR sensor and colour images captured by a CCD (charge-coupled device) sensor, which breaks the image elements into pixels.

The proposed framework comprise two parts: (1) the generation of object-region proposals, including the pre-processing of 3D LIDAR point clouds, extraction and removal of ground points, clustering of non-ground obstacles, calculation of the 3D bounding boxes (BBs) of the clustered obstacles and projection of an image to generate 2D object-region proposals, and (2) a multi-scale CNN-based classifier for classifying the object-region proposal.

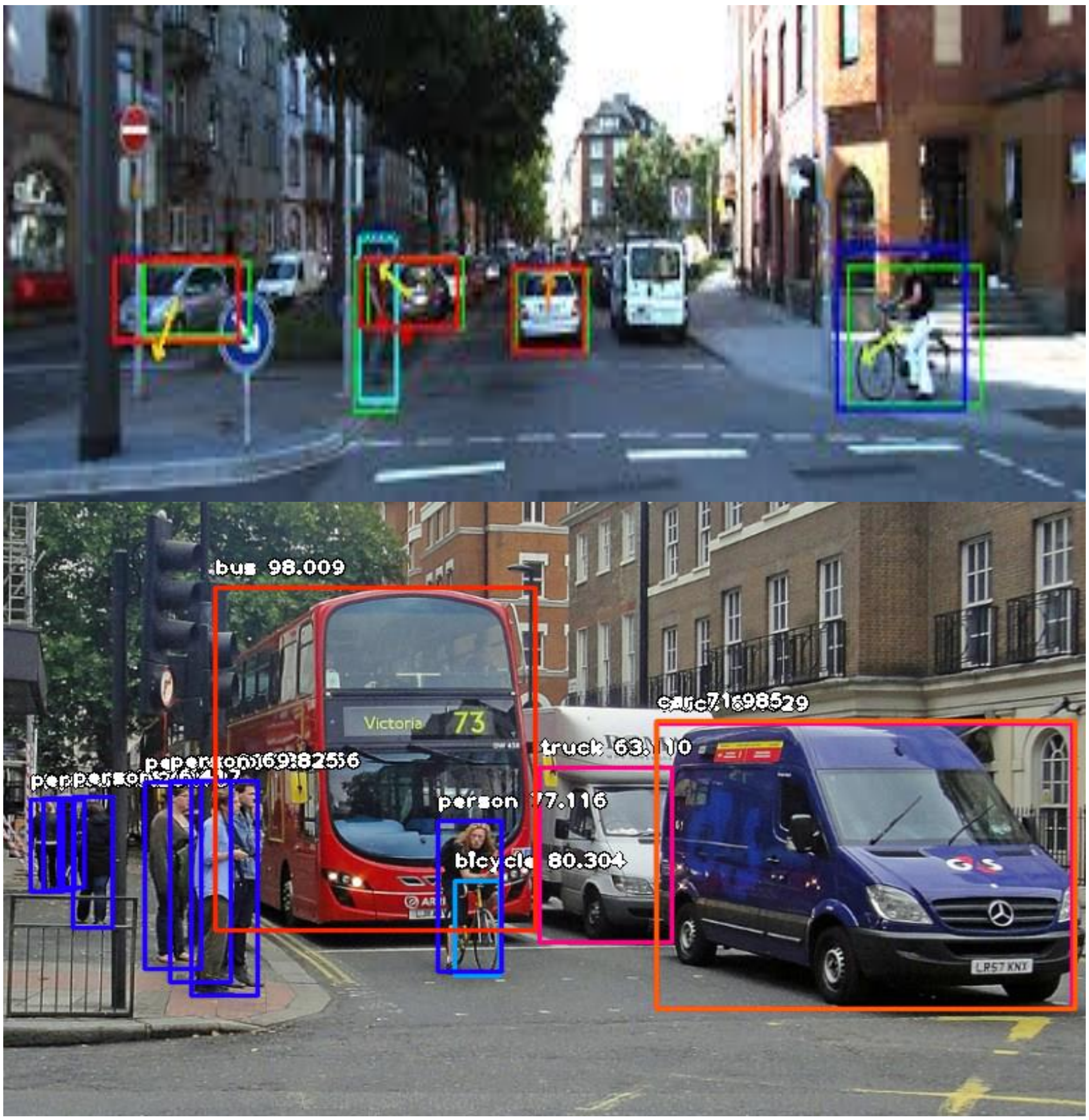
4.1 Object-Region Proposal Generation Using LIDAR Data

To accelerate the detection process, state-of-the-art approaches generally use a proposal generator to generate a set of candidate regions rather than conducting an exhaustive window search. The proposed method only utilizes the 3D spatial information provided by a 3D LIDAR sensor to generate the object-region proposals, following a three step procedure, as described below.

a) **Ground Point Extraction and Removal:** To improve the quality of the object-region proposals and reduce unnecessary computation, the ground points must be removed from the raw point cloud before performing object clustering.
b) **Non-Ground Segmentation:** After removing the ground points, the rest of point cloud needs further segmentation. 3D LIDAR points has the characteristics of sparsity, disorder and non-uniformity. To avoid this problem, we propose a segmentation method based on the continuity.
c) **Region Proposal Generation:** To generate more accurate object-region proposals and ensure better performance of the detector module, we compute the 3D bounding box of each cluster and filter out some dummy objects based on empirical information.

Chapter 5

EXAMPLES OF OBJECT DETECTION RESULTS



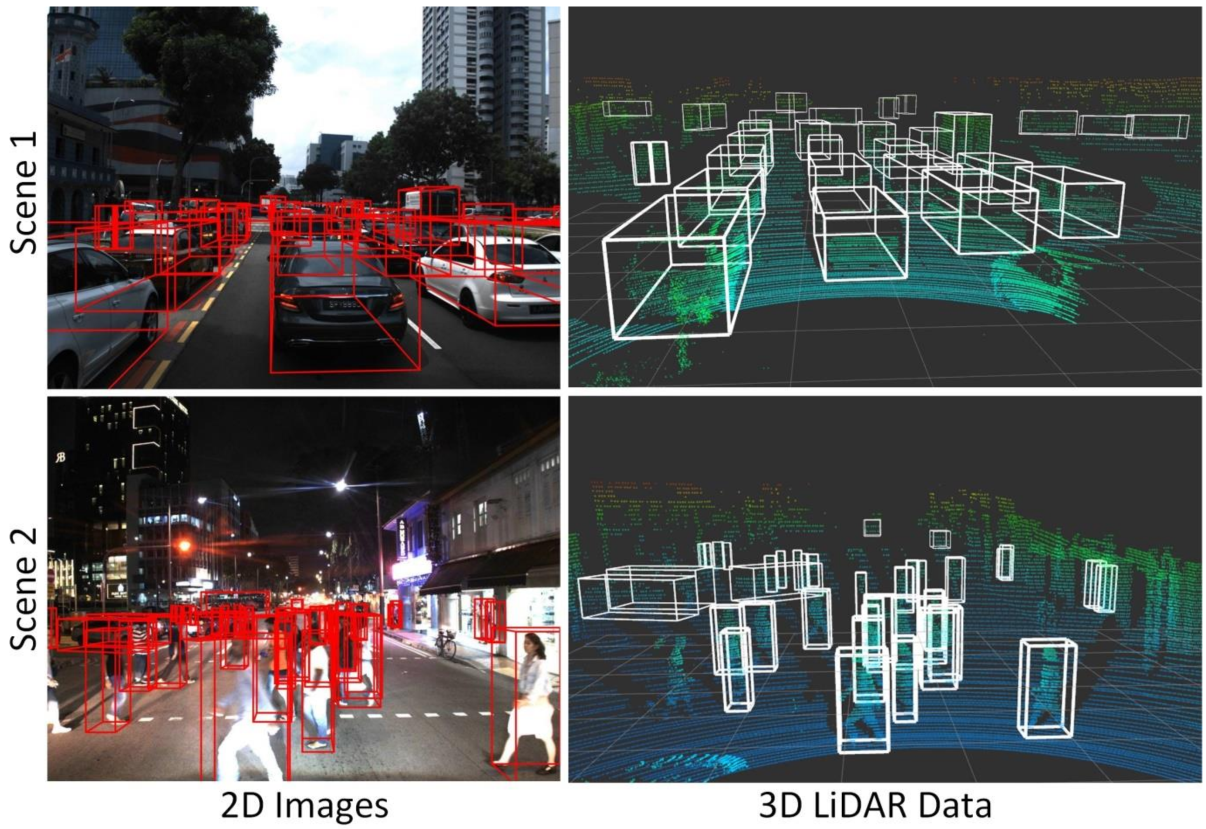


Fig 5.1 Examples of object detection results including pedestrians and cars at various difficulty levels.

Chapter 6

CONCLUSION

Sensor fusion capabilities are a vital component for autonomous driving systems to perceive the world accurately. Sensors such as LiDAR, RADAR, ultrasonic, and camera sensors can individually carry out some detection functions very well standalone, while others can be more of a challenge to perform due to capability weaknesses. Aggregating the strengths across sensors produces higher quality information for autonomous vehicle to run safely.

REFERENCE

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