LeddarTech

SOLVING CRITICAL SENSING, FUSION AND PERCEPTION CHALLENGES

TECHNICAL NOTE

The Need, Techniques and Advantages of Raw Data Sensor Fusion in ADAS and AD for Sensing and Perception

An Overview

This Technical Note explains the need for a raw data sensor fusion-based perception solution for advanced driver assistance systems (ADAS) and autonomous driving (AD) systems. This document explains the principle, configurations and workings of sensor fusion and demonstrates a practical application of sensor fusion in ADAS through attitude estimation and concludes by presenting the commercially available solution in the market today.

What Is Sensor Fusion and Perception?

Sensor fusion is the merging of data from at least two sensors. In autonomous vehicles, perception refers to the processing and interpretation of sensor data to detect, identify, classify and track objects. Sensor fusion and perception enable an autonomous vehicle to develop a 3D model of the surrounding environment that feeds into the vehicle's control unit.

What Is the Need for Sensor Fusion in ADAS and AD Solutions?

Current sensor fusion solutions for ADAS and AD perform object-level fusion wherein each sensor (e.g., radar, camera, LiDAR), with its inherent limitations, identifies and classifies objects individually. This results in poor performance and is not optimal because no single sensor can detect all objects under all conditions. Each sensor has its limitations, and Table 1 below gives an overview of its respective strengths and weaknesses.

Table 1 – Sensor comparison for ADAS & AD applications

	Camera	Radar	LiDAR
Depth perception	Poor	Best	Good
Resolution	Best	Poor	Better
Cost	Low	Low	High
Bad weather performance	Poor	Best	Good
Features	Able to view signs, lanes, colors (RGB)	Long range, low resolution	Medium range, high resolution

A camera performs very well at detecting RGB information, identifying and distinguishing objects, and possesses high resolution. However, cameras do not perform well in poor weather conditions such as fog, snow, rain or sunlight shining against the camera lens, nor do they do well in low-light conditions such as nighttime.

A radar can provide distance and velocity information of objects in the environment. Moreover, radars perform well in poor weather conditions but suffer from a critical issue, i.e., poor resolution. At large distances, radars are unable to distinguish between two objects spaced a small distance apart. This drawback has serious consequences for ADAS safety and reliability. A radar that is unable to distinguish between two different objects could cause the vehicle to continue moving where it should have stopped.

LiDARs overcome radar weaknesses by providing better resolution performance at long distances. However, LiDAR costs are high.

Traditional perception solutions make decisions based on each sensor's understanding of the environment. Raw data sensor fusion uses the raw data from all sensor modalities, which mitigates the individual sensor limitations (e.g., the camera's limitation in poor weather) by leveraging other sensors (radar and/or LiDAR).

Furthermore, when sensor data is not fused, the system may get contradicting inputs from sensors and be unable to determine with a degree of certainty the next course of action. For example, suppose an obstacle is detected by the camera but not by the LiDAR or radar, the system hesitates whether the vehicle should stop, potentially leading to an accident.

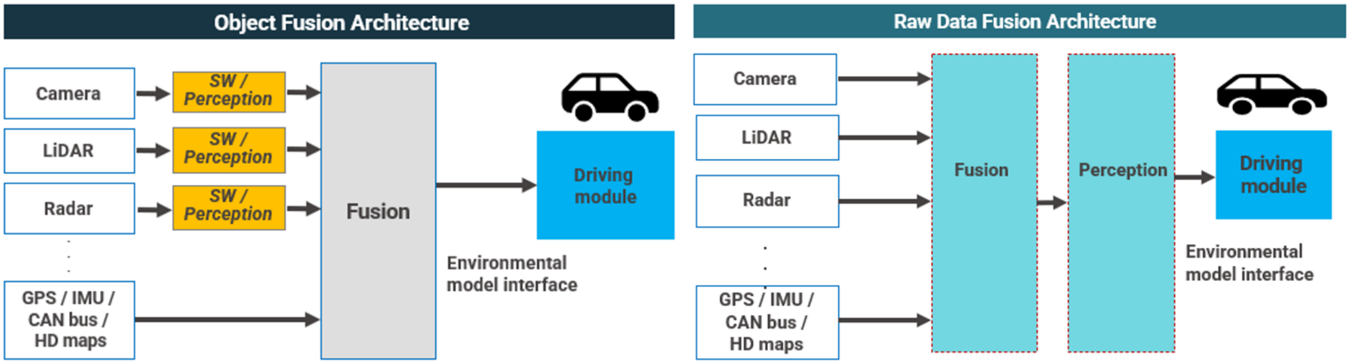


Figure 1 – Comparison between object fusion and raw data fusion architectures

Existing sensor fusion and perception solutions are camera-centric, whereas other sensors are typically fused at the object level. Such 2D camera-based solutions exhibit poor performance in terms of:

- Positioning
- Accuracy
- Object size and orientation estimation
- Object detection under degraded light conditions

Configurations of Sensor Fusion in ADAS and AD

Having established that perception solutions perform better by leveraging sensor fusion, this section delves deeper and explains some techniques used in sensor fusion. As described in scientific literature[1], sensor fusion works in three main configurations.

- **Complementary sensor fusion:** In a complementary configuration, data from each sensor is "stitched" together to provide the complete information required. For example, multiple radars installed on various sides of the vehicle can combine to warn the driver of an object in the vehicle's immediate vicinity, providing 360-degree protective coverage.

- **Competitive sensor fusion:** In a competitive configuration, each sensor delivers the same measurement, and the system processes it to provide a more reliable reading. A significant advantage of such a system is enhanced redundancy since, if one sensor malfunctions, the other can be used for providing the same measurement. For example, a vehicle can be fitted with two speedometers (analog and digital) and the vehicle's actual speed could be determined by averaging the individual sensor outputs.

  Another example of competitive sensor fusion is using a radar and a LiDAR to measure the distance to the next vehicle. Both sensors measure the same parameter and the sensor fusion algorithm processes data from both sensor types. This flexibility in incorporating multiple modalities (sensors) within the sensor fusion algorithm is critical for reliable and safe ADAS and AD. Futuristic sensor fusion and perception solutions for ADAS and AD must be flexible to work with any sensor set without needing to rewrite algorithms.

1 H. F. Durrant-Whyte. "Sensor Models and Multisensor Integration." International Journal of Robotics Research, 7(6):97–113, Dec. 1988. https://netwerkt.wordpress.com/2011/03/30/the-different-types-of-sensor-fusion-complementary-competitive-and-cooperative/

- **Cooperative sensor fusion:** In a cooperative configuration, two sensors provide data that would not have been available using only one sensor. Within the autonomous vehicle context, this can take the form of using stereo cameras for 3D imaging and depth understanding, none of which would be possible using one camera alone.

  Another example of cooperative sensor fusion is to use a camera and radar or camera and LiDAR to develop a 3D RGBD environmental model for object detection, classification and tracking.

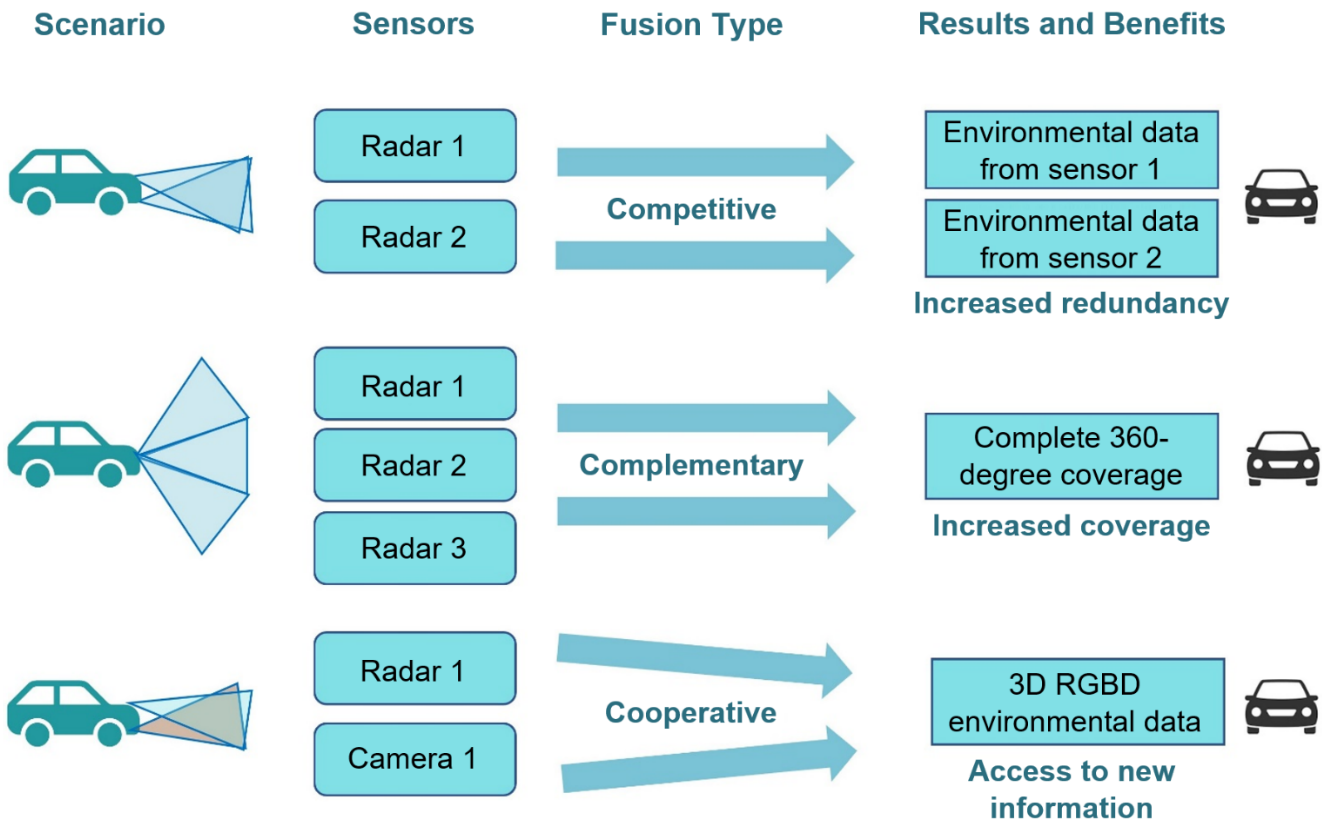


Figure 2 – Competitive, complementary and cooperative fusion techniques

A Theoretical Approach to Attitude Estimation Using Sensor Fusion

Attitude estimation is also known as orientation estimation and forms the basis of inertial measurement unit (IMU) systems. A few definitions are provided below prior to describing how sensor fusion is used in IMU systems.

- **Magnetometer:** A device that measures a magnetic field. In this application, it measures the earth's magnetism.
- **Gyroscope:** A device that measures or maintains an object's angular velocity and orientation.
- **Accelerometer:** A device that measures the acceleration of an object.
- **Roll:** Rotation around the front-to-back (headlight-to-taillight) axis. A vehicle that turns at high speeds, causing one side to lift, is an example of roll movement.
- **Pitch:** Rotation around the side-to-side (left side mirror to right side mirror) axis. A vehicle going over potholes, causing the rear or front of the vehicle to jump, is an example of pitch movement.

- **Yaw:** Rotation around the vertical axis.

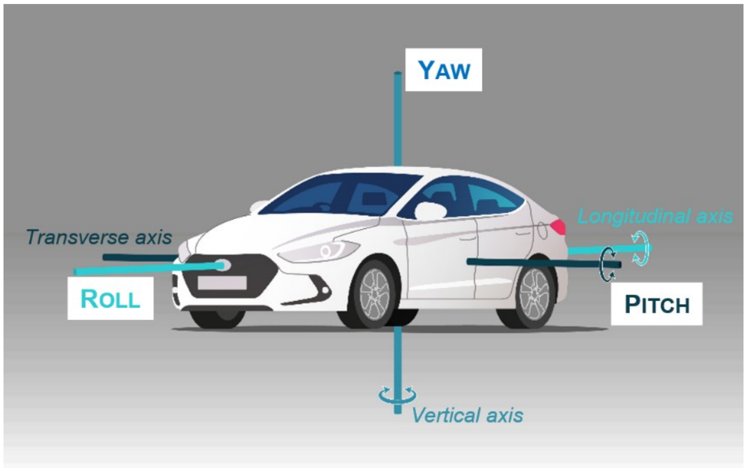


Figure 3 – Illustration of vehicle roll, pitch and yaw axes

An object's position in a 3D environment can be represented by assigning values to the x, y and z axes. Roll, pitch and yaw define the orientation of an object in a 3D space. At time t = 0, if the object's orientation is known, then at time t = 5 (5 seconds later), the object's orientation will be known if the gyroscope, accelerometer, magnetometer (and therefore roll, pitch and yaw) values are known during this interval.

A gyroscope provides roll, pitch and yaw data. Gyroscopes are characterized by low noise. However, they suffer from bias instabilities, resulting in a drift from the true value over time.

Accelerometers provide acceleration data along the x, y and z axes. From this, roll and pitch data can be calculated using the mathematical formulae below:

$$\boldsymbol{Roll} = \boldsymbol{\phi} = \mathbf{arctan}\left({}^{\boldsymbol{a_y}}/_{\boldsymbol{a_z}}\right)$$
$$a_y = acceleration\ in\ y\ direction$$
$$a_z = acceleration\ in\ z\ direction$$

$$\boldsymbol{Pitch} = \boldsymbol{\theta} = \mathbf{arcsin}(\boldsymbol{a_x}/\boldsymbol{g})$$
$$a_x = acceleration\ in\ x\ direction$$
$$g = gravity$$

Similarly, mathematical calculations can be performed on magnetometer readings to provide yaw data.

While a gyroscope alone could provide all the data required (roll, pitch and yaw), the gyro sensor suffers from weaknesses such as bias instabilities and drift over time from the true value and is, therefore, not reliable alone. On the other hand, an accelerometer can provide roll and pitch data; however, accelerometers suffer from high noise. Therefore, to obtain accurate and reliable data, both sensors' data (accelerometer and gyroscope) are fused and can compensate for the other sensor's weaknesses. However, since accelerometers cannot be used to calculate yaw, the yaw value due to gyroscope alone would be inaccurate; therefore, combining data from a magnetometer is useful, adding reliability and confidence to the output data.

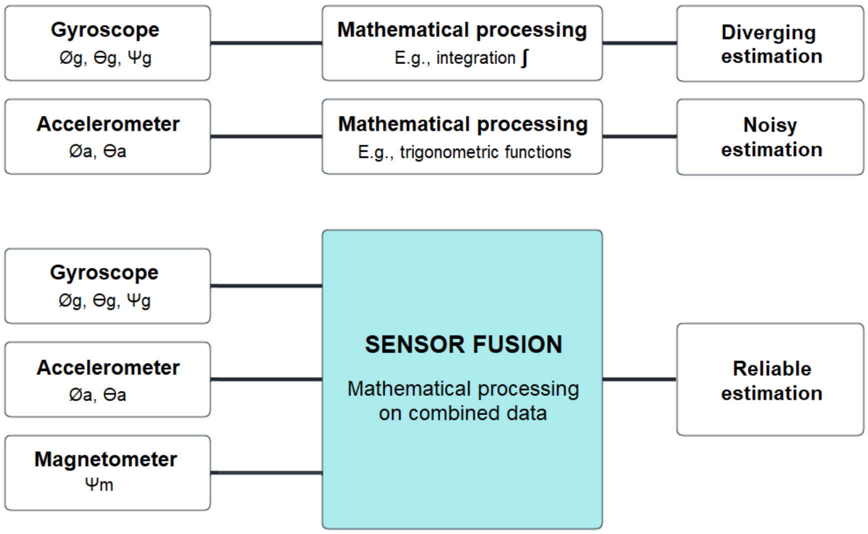


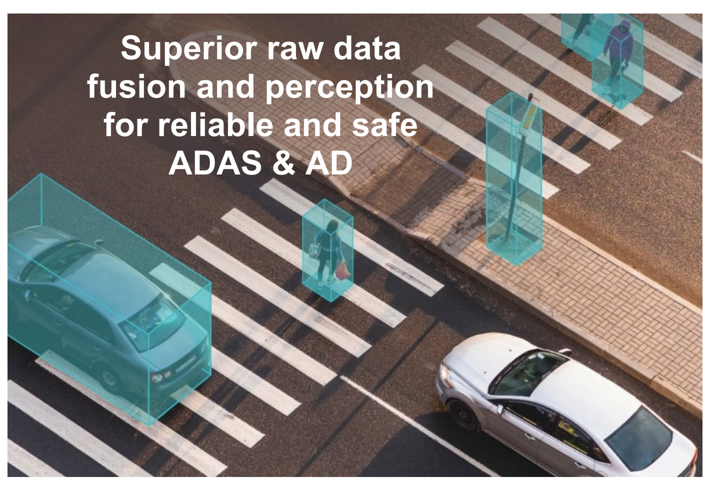
Figure 4 – Benefit of fusing gyro, accelerometer and magnetometer for attitude estimation

Commercially Available Perception Solution for ADAS and AD Based on Sensor Fusion

LeddarVision™ is a raw data sensor fusion and perception solution that generates a comprehensive 3D RGBD environment model with multi-sensor support for GPS, IMU, camera, radar and LiDAR architectures for advanced driver assistance systems (ADAS) and autonomous vehicles.

LeddarVision for ADAS and AD

LeddarVision is based on raw data sensor fusion and offers four distinct advantages to OEMs and Tier 1 and Tier 2 automotive suppliers.



- **Superior performance:** Delivers accurate object detection, classification and tracking.
- **Flexibility:** A hardware-agnostic solution compatible with multiple sensor architectures and support for cameras, radars and LiDARs.
- **Scalability:** Solution designed for scalability. Designed to meet demands of L2, L2+ and L3 ADAS systems as well as L4 and L5 AD systems.
- **Reliability:** Factors include built-in redundancy, safety monitoring as well as solid quality management and product development practices suited for automotive industry standards.

LeddarVision's raw data sensor fusion capabilities, sensor synchronization and upsampling underlie LeddarVision's superior object detection performance and accurate 3D RGBD environmental model reconstruction. LeddarVision adds timestamped temporal information (i.e., information from multiple frames) and performs multiple measurements of a single object, resulting in measurement error reduction and high accuracy. Of all the submissions made between 2019 and 2021 to nuScenes™, LeddarVision's RCF360v2 is the top-ranking radar/camera solution for 3D object detection. LeddarVision is characterized by:

- Accurate and precise detection
- Fewer false positives
- Fewer false negatives
- Ego-motion and path planning
- Superior performance in harsh conditions
- Resolution of conflicting sensor inputs
- Built-in redundancy

Additional resources to learn more about raw data sensor fusion and LeddarVision are available at leddartech.com:

Performance videos

Spec Sheet

Tech E-book on Sensor Fusion and Perception

Perception Technology FAQ

LeddarTech®

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