Automotive ADAS Systems

Overall Automotive ADAS System
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ADAS Overview
Overview of ADAS Technologies
ADAS Sensors - Needed for Perception

- LIDAR
- Radar
- Cameras
- GNSS antenna
- Ultra-Sonics
- Central Computer
- Wheel Odometry
The 5 Levels of Vehicle Automation

Adding Senses
- Accelerometers and Gyro
- Steering Wheel Angle
- Ultrasonic sensors
- Front Radar Sensor
- Blind Spot sensor
- Rear View Cameras
- Front View Cameras
- Surround View Cameras

Levels 0-2
Human driver monitors the driving environment

Levels 3-5
Automated driving "system" monitors the driving environment

Learning to Drive
- Systems Networking
- Sensor Fusion
- Distance Measurement
- Traffic Sign Recognition
- Lane Reconstruction
- Free-path Definition
- Precise Positioning
- Real-time Mapping
- Driving Rules Implementation
- Critical Arbitration

Source: SAE standard J3016
Sensor Fusion is Key to Autonomous

No sensor type works well for all tasks and in all conditions, so sensor fusion will be necessary to provide redundancy for autonomous functions.

<table>
<thead>
<tr>
<th></th>
<th>Camera</th>
<th>Radar</th>
<th>LiDAR</th>
<th>Ultrasonic</th>
<th>LiDAR+Radar+Camera</th>
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<tr>
<td>Object detection</td>
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<td>Object classification</td>
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<td>Distance estimation</td>
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<td>Object edge precision</td>
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<td>Lane tracking</td>
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<td>Range of visibility</td>
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<td>Functionality in bad weather</td>
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<td>Functionality in poor lighting</td>
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Most likely used fusion solution in future: Good, Fair, Poor

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ADAS Vehicle Architectures
Distributed vs Centralized Processing

**Distributed Processing with Object Level Fusion**

- **Sense**
  - Ultrasonic
  - Lidar
  - Radar
  - Camera
- **Intelligent Edge Processing**
  - Processor
- **Late Sensor Fusion**
  - Processor
- **Object Data**
  - Sensor Fusion, Motion Planning, and Driver warnings
- **Think!**
- **Vehicle Dynamics and Control**
- **Infotainment & Cluster**

**Centralized Processing with Raw Data Fusion**

- **Sense**
  - Ultrasonic
  - Lidar
  - Radar
  - Camera
- **Raw Data Capture (I/Q)**
- **No Processing**
- **Early Data from Sensors**
- **Sensor Hybrid Fusion**
  - Processor
- **Think!**
- **Vehicle Dynamics and Control**
- **Infotainment & Cluster**

**Distributed Interfaces**
- ETH, SPI, I2C, CAN, CAN-FD
  - RADAR, Ultrasonic, V2X, IMU, Wheel Odometry, GNSS
  - MIPI(CSI-2), GMSL(Maxim), FPD-Link(TI), PCIe, HDBaseT(Vales)
  - Video Cameras?
  - Lidar?

**Centralized Interfaces**
- ETH, SPI, I2C, CAN, CAN-FD
  - V2X, IMU, Wheel Odometry, GNSS
  - MIPI(CSI-2), GMSL(Maxim), FPD-Link(TI), PCIe, HDBaseT(Vales)
  - Radar, Ultrasonic
  - Cameras
  - Lidar?
Distributed vs Centralized Processing

• What are the Data rates requirements for each sensor?
  • Centralized (i.e. SERDES?) vs Distributed (i.e. ETH?)

• Example: 4-5 Corner Radars are utilized in high end/premium vehicles.
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Vision (Cameras) System
Camera

• Essential for correctly perceiving environment

• Richest source of raw data about the scene - only sensor that can reflect the true complexity of the scene.

• The lowest cost sensor as of today

• Comparison metrics:
  • Resolution
  • Field of view (FOV)
  • Dynamic range

• Trade-off between resolution and FOV?
• Enables depth estimation from image data

All points on projective line to P map to p

One camera

Find a point in 3D by triangulation!

Add a second camera

Left and right images

Source: Sanja Fidler, CSC420: Intro to Image Understanding
The Next Phase for Vision Technology

- From sensing to comprehensive perception
- Machine learning used already for object sensing
- Autonomous driving needs
  - Path planning based on holistic cues
  - Dynamic following of the drivable area
- Deep learning is now being applied
### Machine Vision: ST & Mobileye

**EyeQ3™ 3rd Generation vision processor**
- Detection of driving lanes
- Recognition of traffic signs
- Detection of pedestrians and cyclists
- Seeing obstacles how the human eye sees them
- Adapting cruise speed
- Emergency braking when car ahead slows suddenly

**EyeQ4™ 4th Generation enables**
- Detection of more objects, more precisely
- More features required for automated driving
- Free-space Estimation, Road Profile Reconstruction
- Monitoring of environmental elements (fog, ice, rain) and their safety impact
- Detailed understanding of the road conditions allowing automatic suspension and steering adjustment
- Highly automated vehicles

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**EyeQ5™**

The Road to Full Autonomous Driving: Mobileye and ST to Develop EyeQ®5 SoC targeting Sensor Fusion Central Computer for Autonomous Vehicles
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LiDAR System
LiDAR Technology Overview

• LiDAR (light detecting and ranging, or “light radar”) sensors send one or more laser beams at a high frequency and use the Time-of-Flight principle to measure distances. LiDAR capture a high-resolution point cloud of the environment.

• Can be used for object detection, as well as mapping an environment
  • Detailed 3D scene geometry from LIDAR point cloud

• LiDAR uses the same principal as ToF sensor, but at much longer distances, minimum 75M for “near field” and 150-200M for “far field”.

\[
\text{Measured distance} = \frac{\text{Photon travel time}}{2} \times \text{Speed of light}
\]
LiDAR Techniques

- There are multiple techniques currently under evaluation for LiDAR, including rotating assembly, rotating mirrors, Flash (single Tx source, array Rx), scanning MEMS micro-mirrors, optical phased array.

- From a transmitter/receiver (Tx/Rx) perspective the following technologies need to be developed or industrialized for automotive.
  - MEMS Scanning Micro-mirror technologies
  - SPAD (Single Photon Avalanche Detectors) - Rx
  - 3D SPAD - Rx
  - Smart GaN (Gallium nitride)

- Comparison metrics:
  - Number of beams: 8, 16, 32, and 64 being common sizes
  - Points per second: The faster, the more detailed the 3D point cloud can be
  - Rotation rate: higher rate, the faster the 3D point clouds are updated
  - Detection Range: dictated by the power output of the light source
  - Field of view: angular extent visible to the LiDAR sensor

Upcoming: Solid state LiDAR!
LiDAR Summary

• Autonomous vehicles have been around for quite some time but only now the technologies are available for practical implementations

• No single sensor solution exists to cover all aspects – range, accuracy, environmental conditions, color discrimination, latency etc.
  • Multi-sensor fusion and integration will be a must
  • Each technology attempts to solve the overall problem while having multiple limitations

• Many LiDAR solutions (technologies) are available or being proposed with no clear winners

• Market is still in very early stage of development and experimentation

• When and which technology or system will be widely adopted and mass production starts is still unknown
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Radar Systems
RADAR Technology Overview

- RADAR (Radio Detection and Ranging) is one necessary sensor for ADAS (Advanced Driver Assistance System) systems for the detection and location of objects in the presence of interference; i.e., noise, clutter, and jamming.

- Robust Object Detection and Relative Speed Estimation

- Transmit a radio signal toward a target, Receive the reflected signal energy from target

- The radio signal can the form of “Pulsed” or “Continuous Wave”

- Works in poor visibility like fog and precipitation!

- Automotive radars utilize Linear FM signal, Frequency Modulated Continuous Wave (FMCW)
  - FM results in a shift between the TX and RX signals that allows for the determination of time delay, Range and velocity.

\[
\text{Range (R)} = \frac{\text{Speed of propagation in medium} \times \text{Signal travel time}}{2}
\]
RADAR Techniques

- Comparison metrics:
  - Range
  - Field of view
  - Position and speed accuracy

- Configurations:
  - Wide-FOV: Short Range
  - Narrow-FOV: Long Range

Definitions:
- Imaging Radar: Forms a picture of the object or area
- Non-Imaging Radar: Measures scattering properties of the object or area
- Primary Radar: Transmits signals that are reflected and received
- Secondary Radar: Transponder that responds to interrogation with additional info
- Pulsed Radar: High power signals are only present for a short duration and repeated at specific intervals
- CW Radar: Signal is present continuously

Source: Strategy Analytics Lunch & Learn the Market Session European Microwave Week 2013
Automotive Radar Vs. Automation Levels

<table>
<thead>
<tr>
<th>Year</th>
<th>Automation Level</th>
<th>Applications</th>
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<tbody>
<tr>
<td>&lt; 2014</td>
<td>Level 1: Driver Assistance</td>
<td></td>
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<tr>
<td>2016</td>
<td>Level 2: Partial Automation</td>
<td></td>
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<tr>
<td>2018</td>
<td>Level 3: Conditional Automation</td>
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<tr>
<td>2019 / 2020</td>
<td>Level 4: High Automation</td>
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<tr>
<td>&gt; 2028</td>
<td>Level 5: Full Automation</td>
<td></td>
</tr>
</tbody>
</table>

- **Object Detection**
  - 2x SRR
  - 2x SRR
  - 4x SRR
  - 4x SRR-MRR
  - 2x USRR

- **Target Separation**
  - 1x LRR
  - 1x LRR
  - 1x LRR
  - 2x LRR

- **3D Detection**
  - 4x SRR
  - 4x SRR-MRR
  - 4x SRR-MRR
  - 4x SRR-MRR

- **360° Object Recognition**
  - MRR
  - MRR
  - MRR
  - MRR

- **Applications**
  - BSD, LCA
  - BSD, RCW, LCA
  - BSD, RCW, LCA
  - BSD, LCA, RCTA
  - BSD, LCA, RCTA
  - BSD, LCA, RCTA

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**USRR** - Ultra Short Range Radar  
**SRR** - Short Range Radar  
**MRR** - Medium Range Radar  
**LRR** - Long Range Radar  
**BSD** - Blind Sport Detection  
**LCA** - Lane Change Assist  
**RCW** - Rear Collision Warning  
**ACC** - Adaptive Cruise Control  
**AEB** - Automatic Emergency Breaking  
**FCW** - Forward Collision Warning  
**RCTA** - Rear Cross Traffic Alert  
**AVP** - Automated Valet Parking  
**PA** - Parking Assist

Source: Rodhe & Schwarz - Automotive radar technology, market and test requirements, White paper – Oct 2018 (Salvo S. presentation)
Automotive ADAS Systems

GNSS/IMU System
GNSS/IMU Positioning

- Global Navigation Satellite Systems and Inertial Measurement Units

- Direct measure of vehicle states
  - Positioning, velocity, and time (GNSS)
    - Varying accuracies: Real-time Kinematic (RTK-short base line), Precise Point Positioning (PPP), Differential Global Positioning System (DGPS), Satellite-based augmentation system (SBAS-Ionospheric delay correction)
  - Angular rotation rate (IMU)
  - Acceleration (IMU)
  - Heading (IMU, GPS)
Precise Positioning to enable < 30cm precision

- Lane detection
- Positioning data for V2X sharing
- Collision avoidance
- Autonomous parking
- Autonomous driving
- eCall accident location
Higher integrity requirements across safety-critical applications

- Semi- and Autonomous driving safety-related applications requirements **increase**
  - Higher safety levels
  - Added redundancy
  - More Robustness & integrity
  - Security

- **Teseo APP** (ASIL Precise Positioning) GNSS receiver, new sensor based on **ISO26262** concept with unique **Absolute and Safe** positioning information complementing relative positioning other sensor inputs (i.e. LIDAR, RADAR, etc.)

**ST’s GNSS Receiver Family for ADAS and AD**

*Courtesy of Hexagon PI*
Precise GNSS is a Critical ADAS Sensor

GNSS Accuracy in Automotive Environment (using PPP – Precise Point Positioning)

Single Frequency (i.e. L1) multi-constellation/code-phase(1msec modulation signal)

Multi Frequency (i.e. L1, L2) multi-constellation/carrier-phase

APP: ASIL Precise Positioning
SWPE: Software Positioning Engine
Precise GNSS is a Critical ADAS Sensor

GNSS Integrity – Protection Levels

Horizontal Position Error and Protection Level

Horizontal Position Error and PL CDF
Automotive ADAS Systems

V2X System
Vehicle-to-Everything (V2X)

- **V2V** Vehicle-to-Vehicle
- **V2I** Vehicle-to-Infrastructure
- **V2M** Vehicle-to-Motorcycle
- **V2D** Vehicle-to-Device/object
- **V2P** Vehicle-to-Pedestrian
FCC Spectrum Allocation for DSRC of ITS

- **Channel 172**: Collision Avoidance Safety (V2V) & Safety of Life
- **Channel 174**: Shared Public Safety/Private Service
- **Channel 176**: Shared Public Safety/Private Service
- **Channel 177**: Control Channel
- **Channel 178**: Announces Services on other channels
- **Channel 180**: Shared Public Safety/Private Service
- **Channel 182**: Shared Public Safety/Private Service
- **Channel 184**: Dedicated Public Safety

- **Reserved Unknown EIRP**
- **EIRP [dBm]**
- **Effective Isotropic Radiated Power**
- **ITS**: Intelligent Transportation Systems

- **Source:** Federal Communications Commission FCC 03-324

- **BSM (V2V)**
- **MAP Message (V2I)**
- **SPAT (V2I)**
- **TX Power +20dBm**

- **Gov’t Only use Limit**

- **Road authorities and public agencies primarily responsible for usage**

**EIRP [dBm] (not to scale)**

- **Frequency [GHz]**
Wireless Access in Vehicular Environments (WAVE)

- Amendment to IEEE 802.11-2012 to support WAVE/DSRC
- No authentication, no access point/no association
- 5.8 – 5.9 GHz OFDM

- Fast Network Acquisition & low latency (<50msec)
- Priority for Safety Applications
- Interoperability
- Security and Privacy (ensured through a root certification system)

Broadcasts BSMs 10 times per second
- Transmit power are about 100mW (20dBm @Antenna Port - Per IEEE802.11-D.2.2 Transmit power level) with a nominal range of 300m (360° coverage)
- DSRC units share the same channel
• C-V2X is a V2X radio layer:
  • C-V2X is Device-to-Device (D2D) communication service added to the LTE Public Safety ProSe (Proximity Services) Services
  • C-V2X makes use of the D2D interface – PC5 (aka Side Link) for direct Vehicle-to-Everything communication
  • C-V2X takes the place of DSRC radio layer in relevant regions
  • V2V, V2I and V2P

ITS Layers Remain Unchanged!
C-V2X Basics

• C-V2X Transmission Mode 4:
  • **Mode 4** – Stand alone, distributed
  • Uses GNSS for location and time for synchronization
Transmission Mode 4:
- Out of Coverage operation: The transmitting vehicle is not connected to the network
- No SIM card or inter-operator collaboration is required
- Each vehicle performs its own scheduling and allocation
- No dependency on inter-vehicle components (eNB, Allocation Server etc…)
- Mandatory for SAE, ETSI
C-V2X Air Interface

• C-V2X is based on LTE (4G) uplink transmission - SC-FDMA (Single Carrier Frequency Division Multiple Access) signal:
  • A single carrier multiple access technique which has similar structure and performance to OFDMA
  • Utilizes single carrier modulation and orthogonal frequency multiplexing using DFT-scaping in the transmitter and frequency domain equalization in the receiver
  • A salient advantage of SC-FDMA over OFDM/OFDMA is low Peak-to-Average Power Ratio (PAPR). Enables efficient transmitter and improved link budget
Both Technologies will do the JOB!

But:

- Industry is waiting for regulatory certainty, Government Mandate is preferred!
- C-V2X has to reach automotive production maturity
- Implementation and deployment will depend on OEM system architecture
- The market will demand standalone V2X module for OEMs and aftermarket because V2X is a safety critical sensor.
Automotive ADAS Systems

Sensor Fusion Example
Multi-sensor Fusion for State Estimation

Extended Kalman Filter
IMU + GNSS + LIDAR

Source: "State Estimation and Localization for Self-Driving Cars", Coursera by University of Toronto