Sensors and In-Vehicle Communications for ITS

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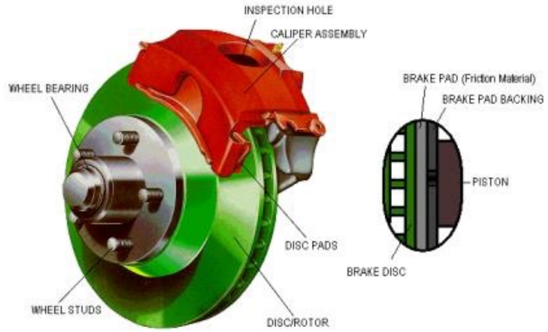
Intelligent Safety Systems and Sonsors

- Intelligent safety systems:
  - *sense* real-world conditions and adjust their performance accordingly.

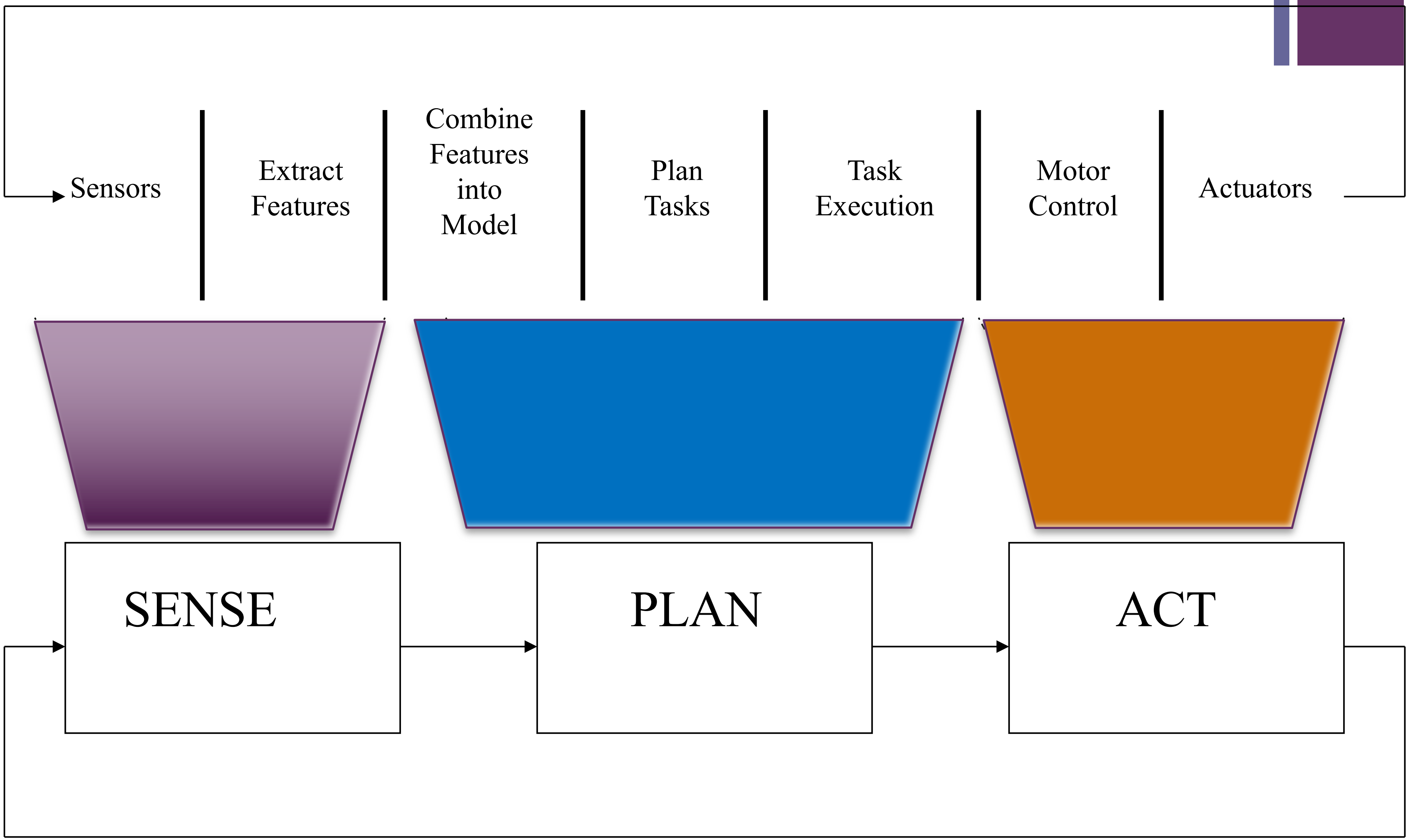


- Example:
  - Conventional braking system
    - brake pressure is determined **solely by how hard** the driver presses the pedal.
  - In an intelligent braking system,
    - the system **sense** whether an object in the vehicle's path and **apply or assist** with braking appropriately.

3 steps

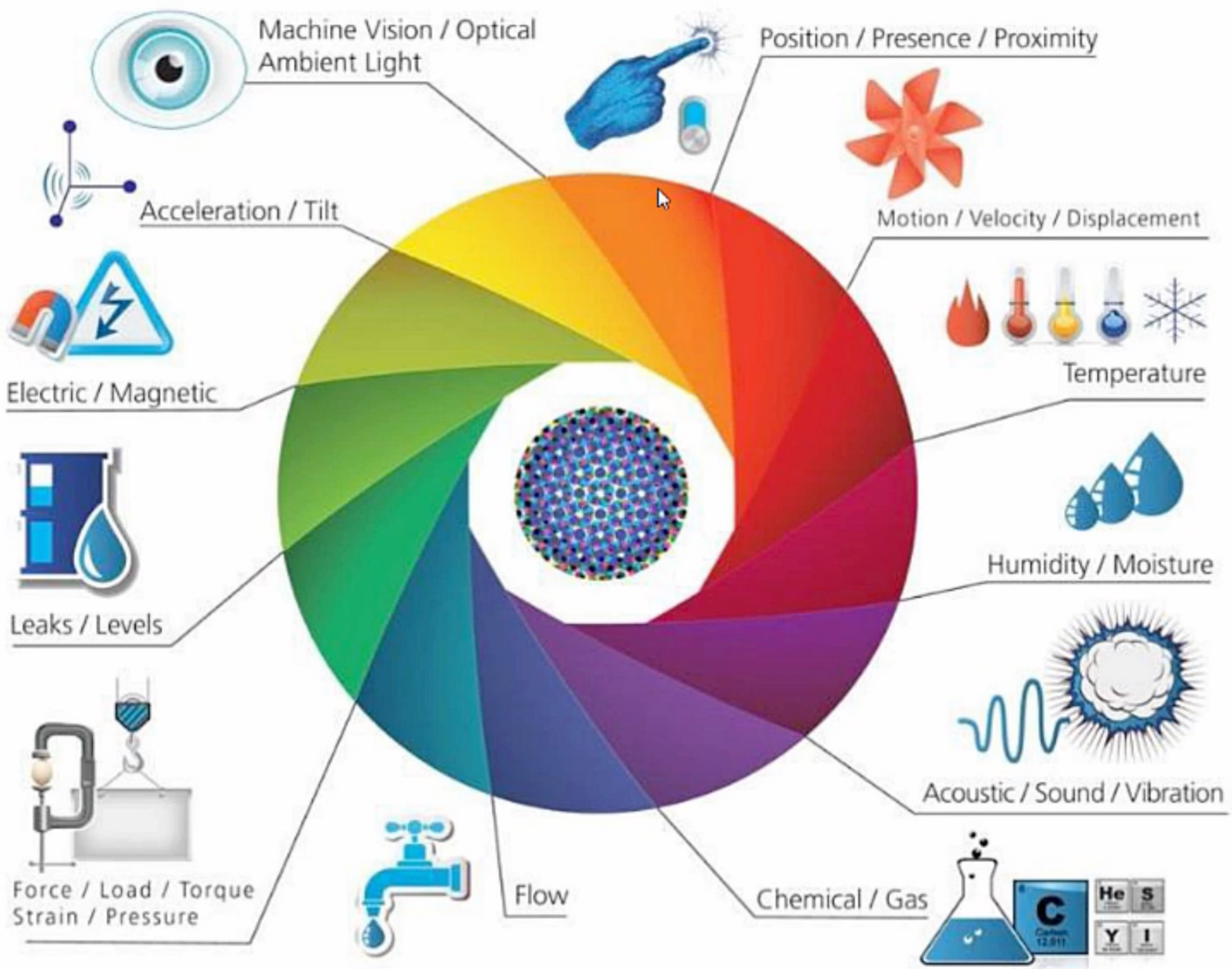
- **Sensing**: Understanding the surrounding environment
  - Example: Where in the lanes, other cars, pedestrians.
  - Example: I am in city center, I have to reduce my speed, likely more pedestrians.
  - Example: I saw a breakdown truck, there is probably an accident, traffic jam, etc.., I must reduce the speed
- **Planning:** Decision making in the context of the other road users. Sequence of actions.
- **Acting:** Moving the car according to the planning

Sensing, Planning & Acting



1 SENSORS & ACTUATORS

We are giving our world a digital nervous system. Location data using GPS sensors. Eyes and ears using cameras and microphones, along with sensory organs that can measure everything from temperature to pressure changes.



Sensors & Computing Data

- Sensor(s) collect(s) data about real-world conditions.
- Planning (Processing)
  - receives data from the sensor as input,
  - makes a decision, and
  - sends commands to acting (vehicle subsystems: engine, braking, audio system to warm the driver);
    - Ex : to prevent an accident, mitigate its severity, or protect the vehicle occupants
- Processing decide that collision is imminent and send a command to the vehicle subsystems to apply brakes.

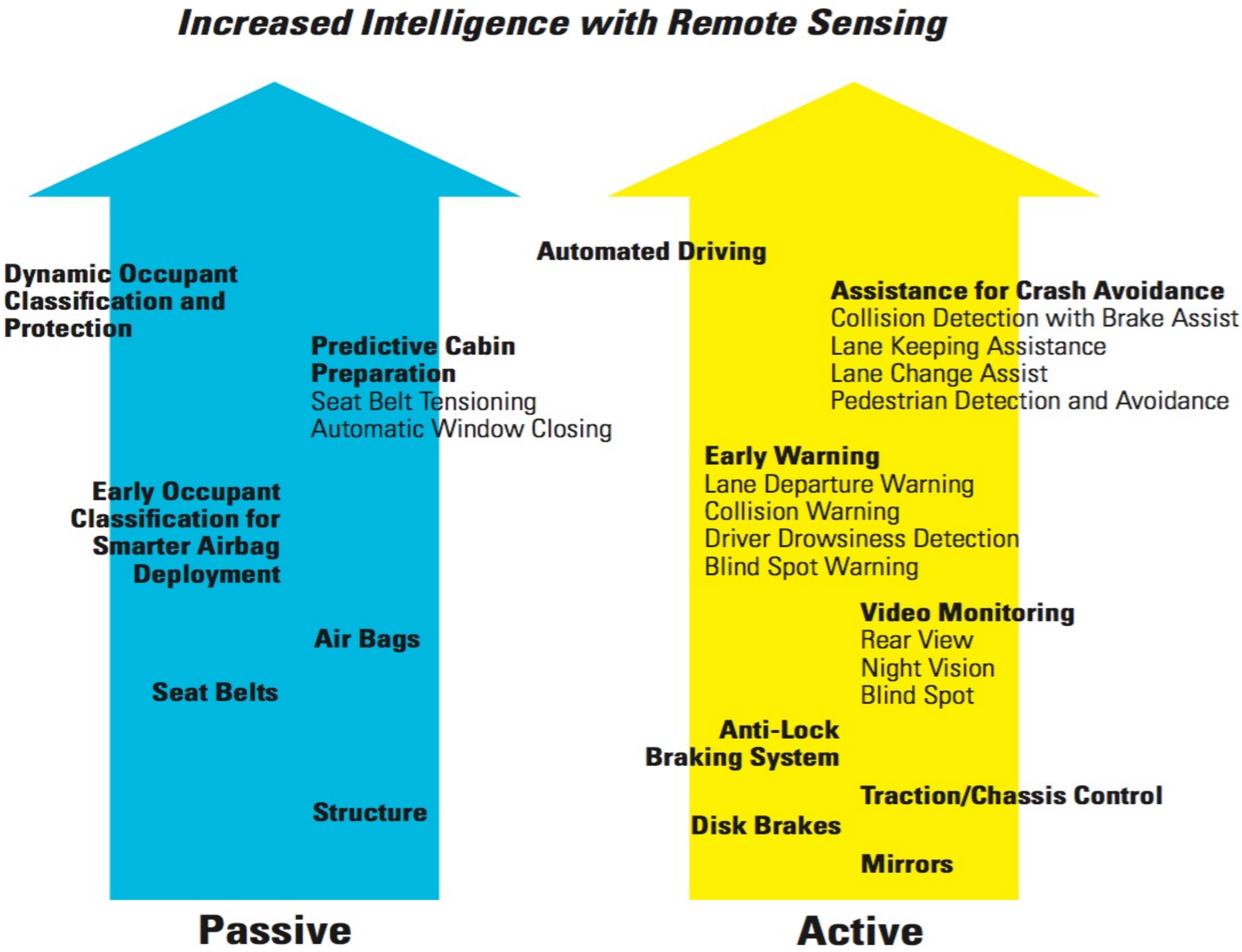
+ Passive Safety Systems

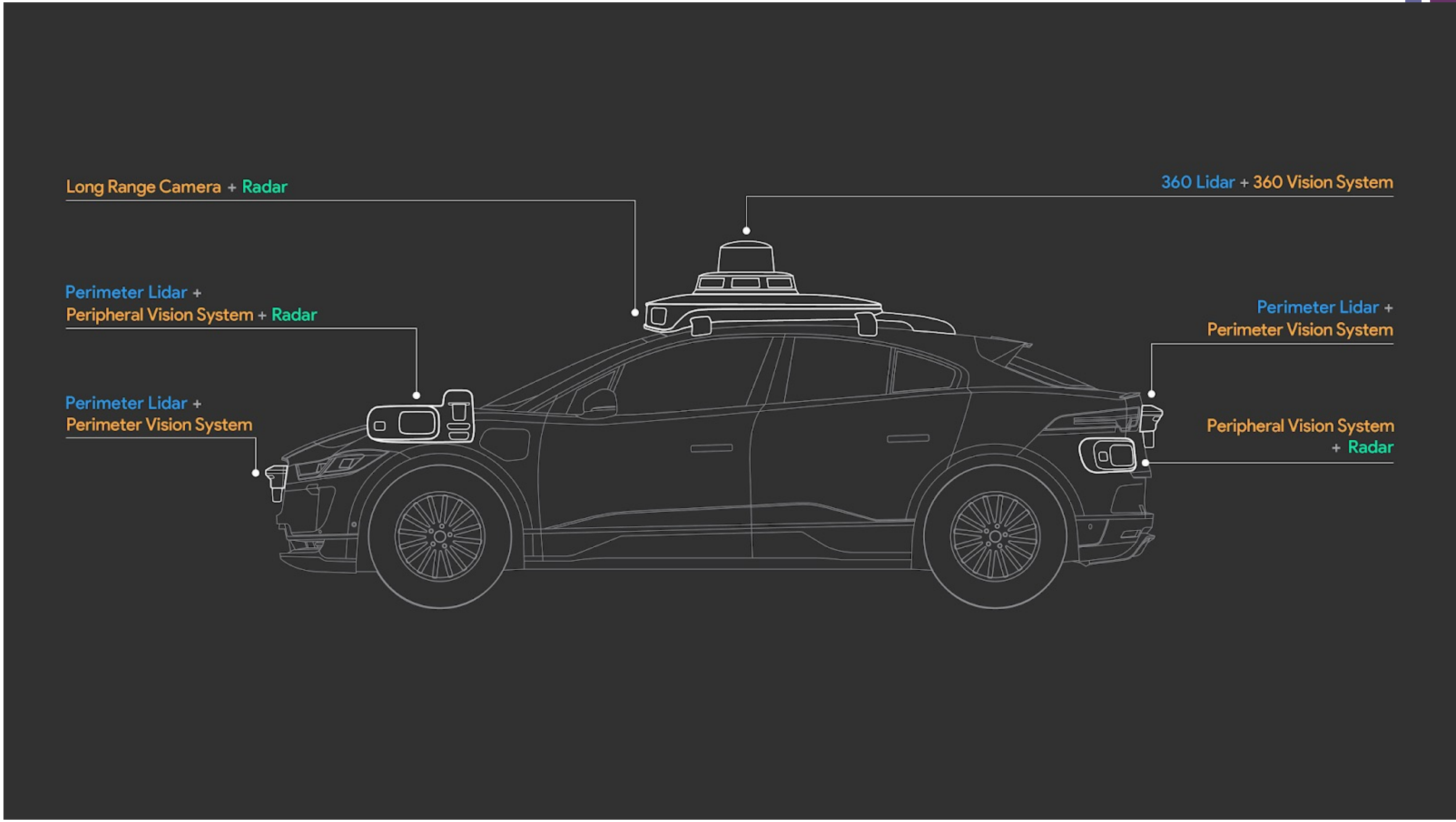
- In **passive safety** systems, sensing information about a possible crash before the impact occurs and take steps earlier to mitigate the outcome.
  - Example: a pre-crash sensor can detect an object in collision range and initiate a change in seat belt tension before impact.
  - Or, a camera that monitors vehicle occupants can determine whether it is safe for an airbag to deploy.

+ Active Safety Systems

- In **active safety systems**,
  - sensing to prevent an accident from happening, or
  - mitigate the severity if an accident is inevitable.
  - Ex : A lane departure warning system, determine if the car is moving outside of its lane, alerting the driver about the lane change.

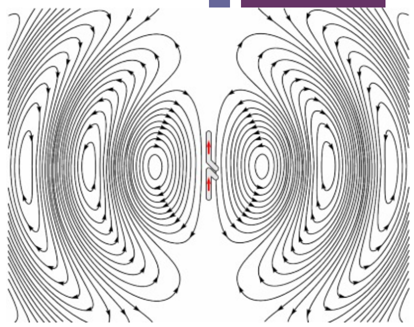
+ Advanced Sensing and Safety Systems



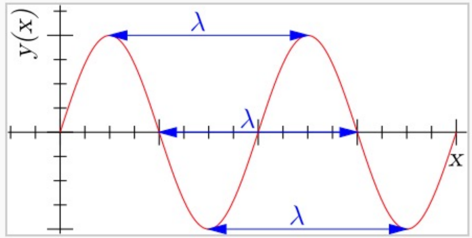


https://www.youtube.com/watch?v=B8R148hFxPw&t=30s&ab_channel=Waymo

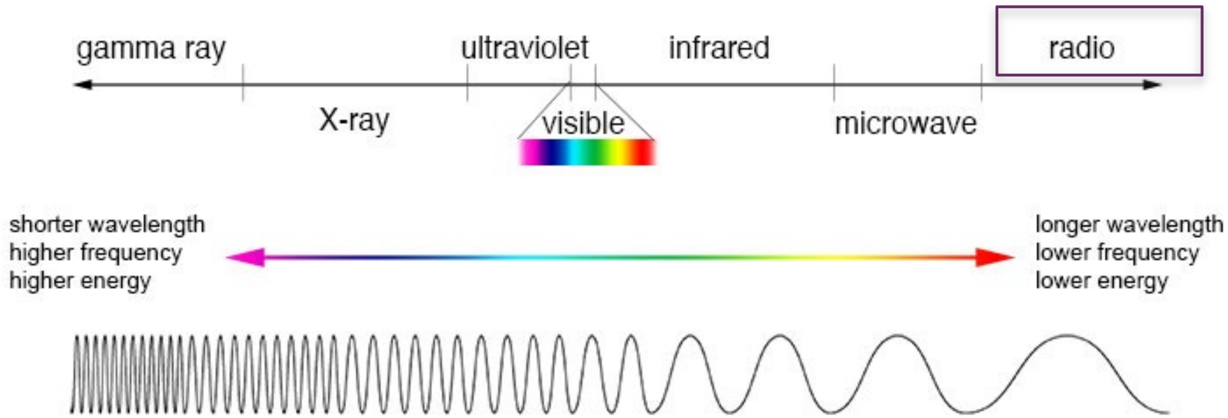
RADAR



- Radar is an object-detection system
  - Uses radio waves, determine the location, size and velocity of objects.
  - Radio waves: electromagnetic radiation with wavelengths in the electromagnetic spectrum longer than infrared light



Wavelength of a sine wave, λ, can be measured between any two points with the same phase, such as between crests, or troughs, or corresponding zero crossings as shown.



+ Radar in the Nutshell

Radar has 2 parts: Transmitter & Receiver

1. Transmits radio waves reflect from any object
2. Receives and processes these reflected waves to determine properties of the object(s).

Power of the Received Signal (Pick = Distance)

Why Radar is interesting ?

- **Most appropriate technology for automotive applications**
  - Less affected by weather conditions and pollution
  - Invisible mounting behind EM-transparent material possible
  - Unaffected by external illumination
  - Flexible and wide application field possible
- **Radar signals have a high information content**
  - Distance and speed information
  - Additional information extraction possible with advanced techniques: object characterization or identification by **radar signature**

Diversified Radar Market

- Different Radar applications (ACC, Lane departure, Pedestrian), require different Radar System parameters and contribute to the diversity:
  - Range, Range Resolution/Accuracy
  - Field of View (FOV), Angular resolution
  - Velocity, Velocity Resolution/Accuracy
  - Response Time
  - Number of objects, object separation, object classification.

Radar Pulse Repetition

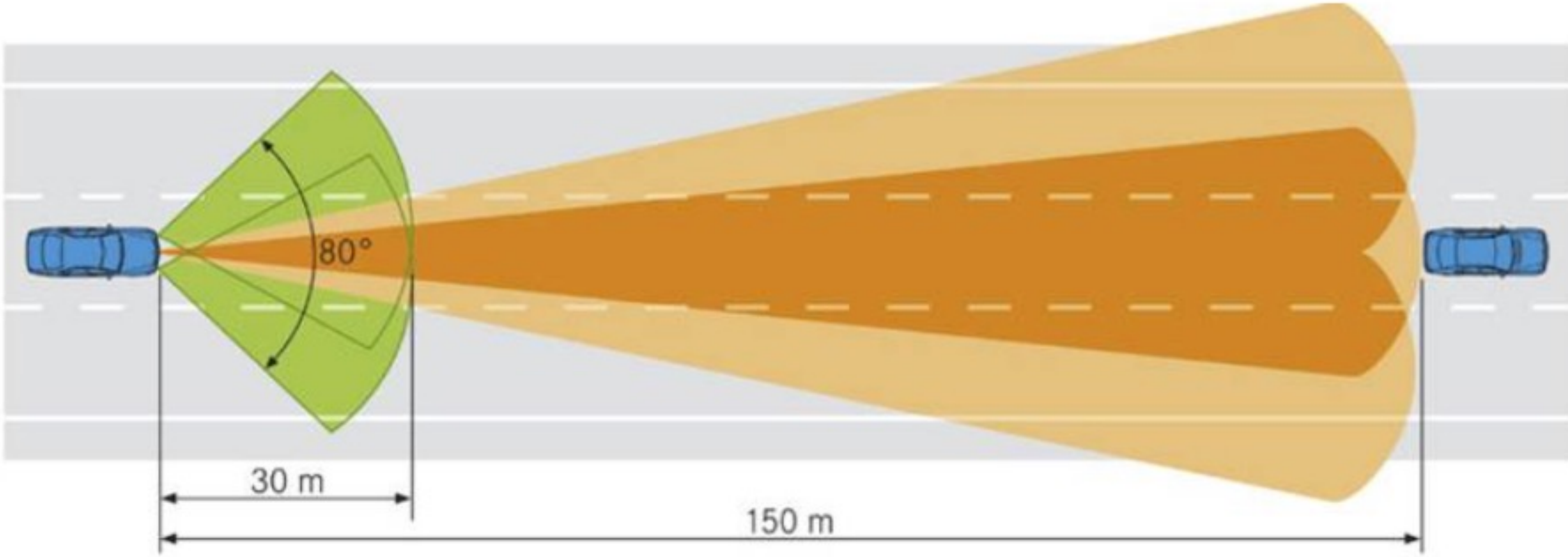
- **The radar Pulse Repetition Time (PRT)** is the time duration between two successive radar scans.
- PRT: *time window within which the tracking system must complete the processing of the information received during a scan*.
- After this interval new observations are available for processing.

- PRT imposes an **upper limit on the latency** of the slowest module in the application.

AC20

- Radar is mounted on the front side of the host vehicle to detect obstacles 200 meters ahead and within the 12° coverage angle.
- MTT behind the radar tracks these obstacles in realtime.
- Target the 66.9% frontal collision zone and warning signals 200 meters before obstacle.
- Driver has more than the half second to react and take a preventive action.

DISTRONIC Plus in the New Mercedes Benz S-Class

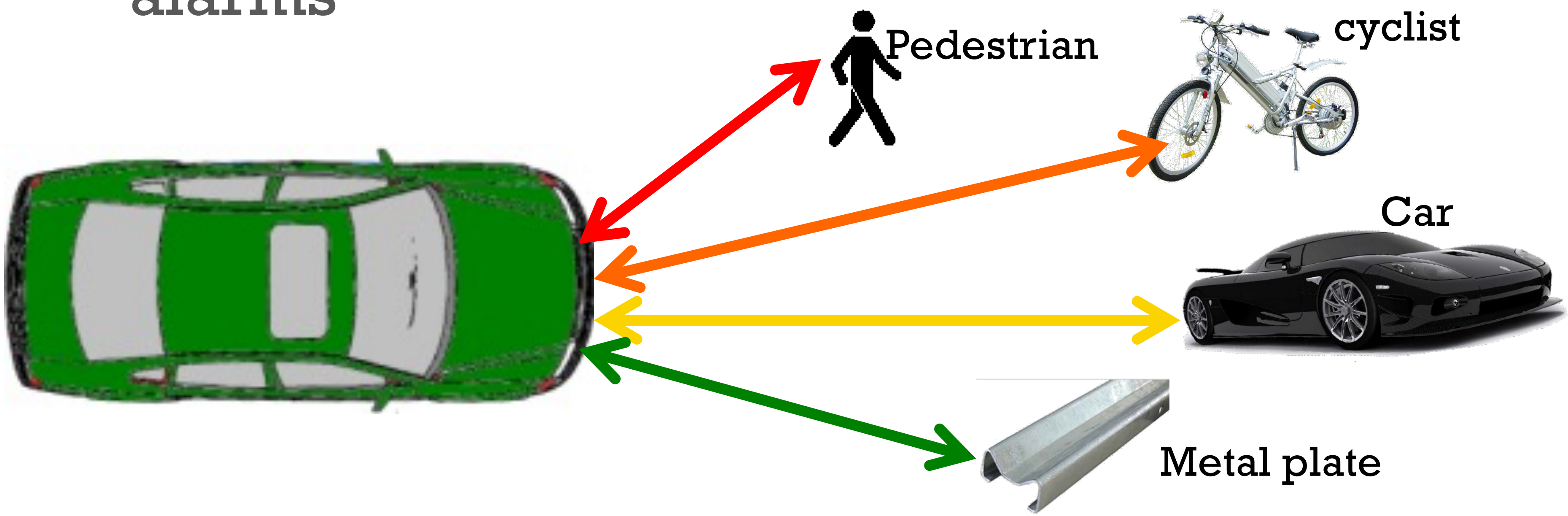


Combination of

- 76.5 GHz Long Range Radar (DISTRONIC)
- 6 x 24 GHz Ultra-Wide-Band (UWB) Short Range Radar

Obstacle Radar Signature (ORS)

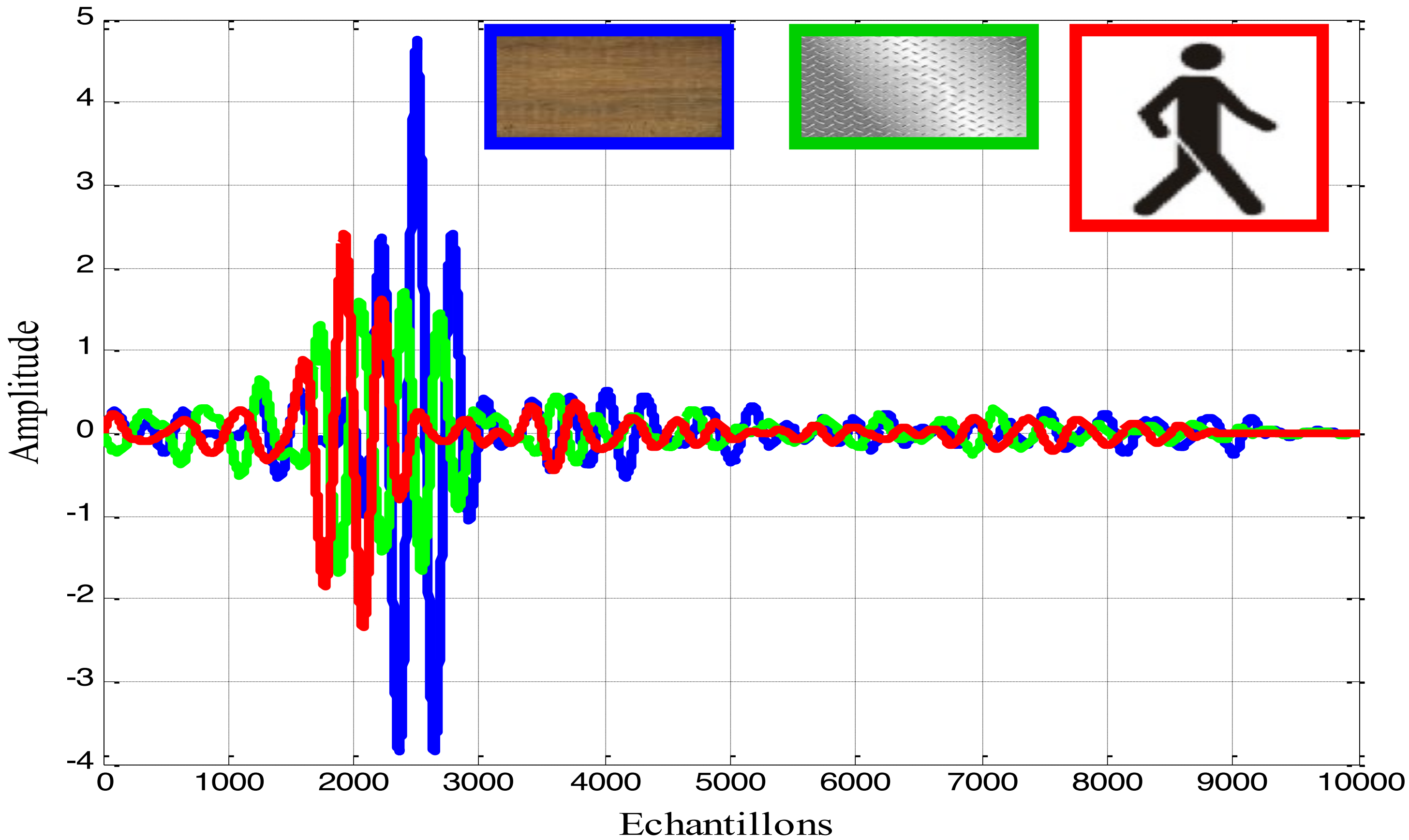
- ORS recognition: adequate alarm → type of the obstacle & degree of dangerousness
- Obstacle identification eliminates false alarms



Comparison of signal detected with 3 obstacles

Correlation with the same reference (wood plate)

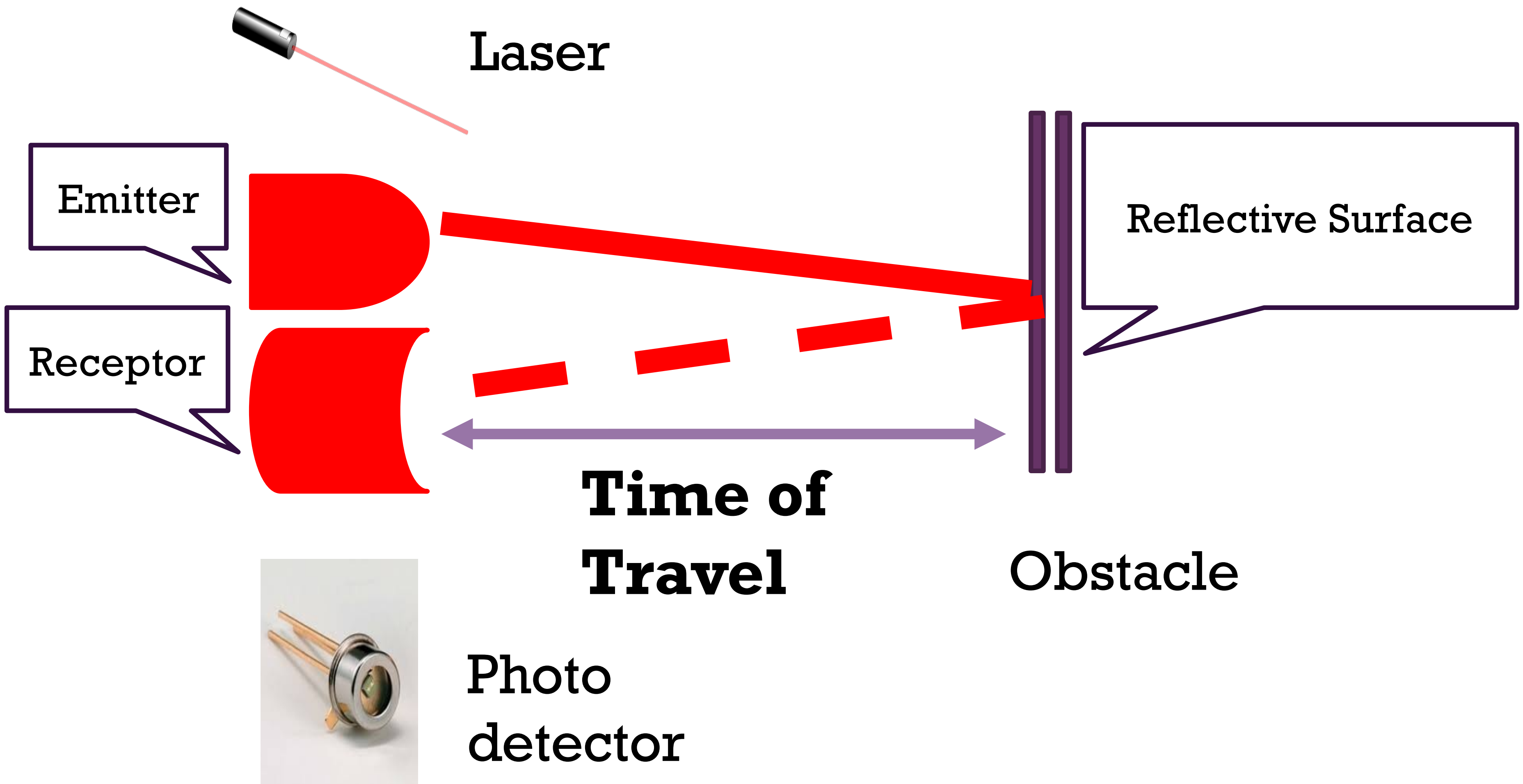
Correlation with others Ref



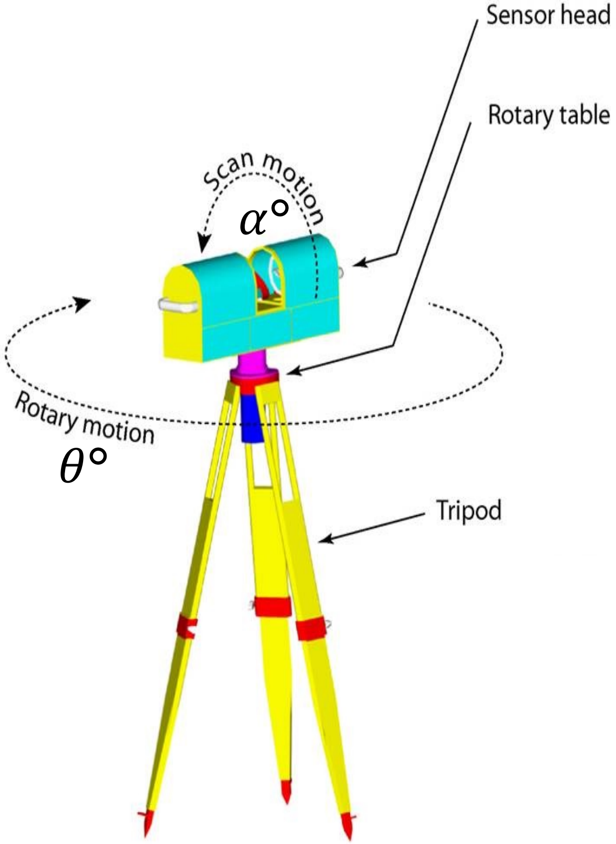
+ LIDAR: Working Principle

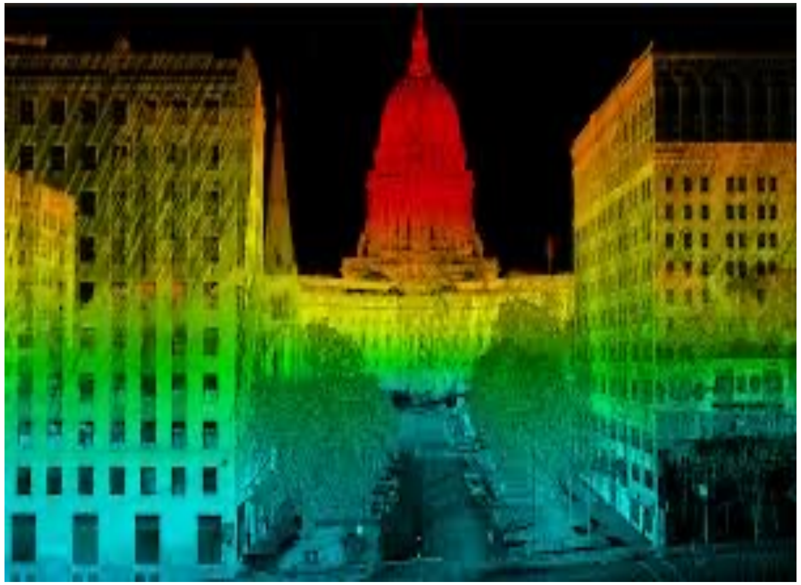
- Principle similar to Electronic Distance Measuring Instrument (EDMI),
  - A laser pulse is fired from a transmitter and the reflected energy is captured.
  - Using the time of travel (ToT) the distance between the transmitter and reflector is determined.

Working Principle



Working Principle





Working Principle

- When impulse is returned to the LIDAR, the received signal can be treated in two ways:
  - Single Return.
  - Dual Return.
- Wavelengths in LiDARs 1000 x shorter Vs. mm radio waves Radar
- Provides higher bandwidth: higher resolution increased safety.

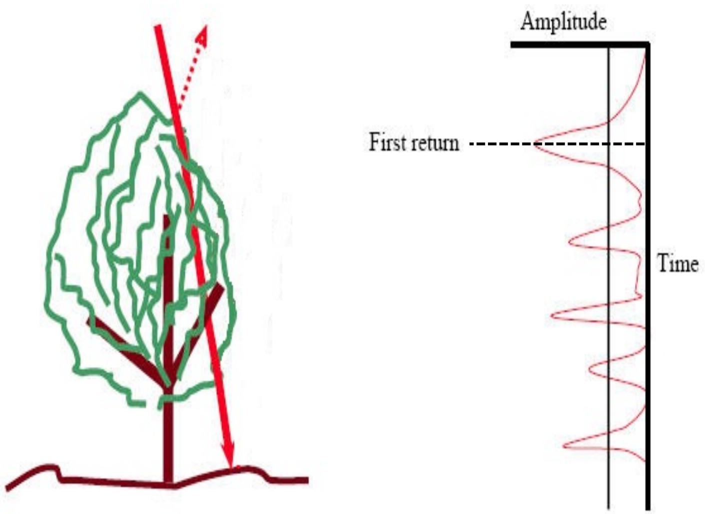
Single Return vs Dual Return

Single Return :

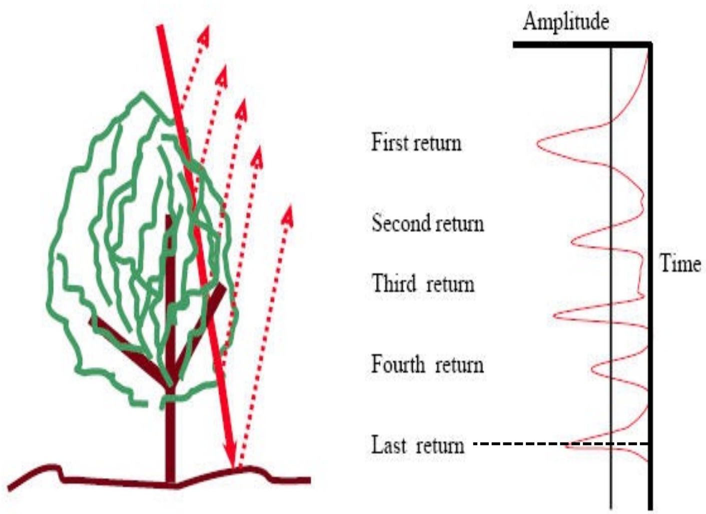
In this mode, Only the first peak is treated, and the rest is discarded.

Dual Return :

The LIDAR waits for a fixed amount of time to see if there is more peaks. This mode help improve the resolution of the LIDAR.



Single Return



Dual Return

+ Cameras in Transportation Systems

- In 1rst generation of vision-based systems:
  - General-purpose cameras used, not designed specifically for automotive applications.
  - Do not stand up to the automotive environment and do not provide the necessary high level of performance.
- Future of automotive vision provide a higher level of performance than general-purpose cameras,
  - Meeting automotive quality standards
  - Providing low unit costs at high volume.
- Development and manufacture of such cameras is not a trivial
  - undertakes and presents many unique challenges.

Cameras in Transportation Systems

- Cameras play an important role
- Rear view enhancement is common implementation of a vision-enabled application
- Must perform well in automotive applications
  - In all conditions of intensity, illumination, wavelengths, speed of motion.
  - Reliability and cost effectiveness.
    - Cameras must be commercially available at volume costs and built to last for long life in a rugged environment.

Charge Coupled Devices (CCDs) Cameras

- CCDs are well suited to numerous applications,
  - but have inherent draw-backs for transportations systems.
- Do not provide the necessary wide dynamic range.
- If dynamic range of a camera not sufficiently wide:
  - Image will fail to capture details
  - Most of these details cannot be recovered through post-processing.

Figure 2. Images captured without (left) and with (right) Wide Dynamic Range

CCD Camera Limitations

- Standard CCD image sensors are designed for serial readout: all previous pixels must be read out before the next pixels can be read.

+ CMOS Image Sensors

- Complementary Metal Oxide Semiconductor (CMOS) is replacing CCD.
- CMOS cameras are capable of meeting the requirements for **wide dynamic range**
  - Can handle bright and dark conditions; + quality
- Economy of scale, with comparable image quality.
- Random access readout: pixels can be randomly addressed, sub-frame quickly read out.

+ High Imaging Sensitivity

- Higher sensitivity of sensor = less light needed to capture a good image.

Figure 10

Low-light scene requires a camera with high imaging sensitivity

+ Comparaison

Table 1 Comparison of Remote Sensor Types

Sensor type	Key Advantages
Cameras (vision)	• Variable field of view (FOV), narrow to panoramic • High spatial resolution • Color data • Low unit volume costs • Non-emitting • Configurable for multiple applications
Radar	• Wide FOV • High range resolution • Operates in adverse weather conditions • Operates over significant distances
Laser (lidar)	• Wide FOV with angular resolution • Ranging • High accuracy
Ultrasonic	• Ranging for short distances • Low unit volume costs
Thermal cameras	• Passive/non-emitting • High temperature resolution

+ Comparaison

Performance aspect	Human	AV			CV	CAV
		Radar	*Lidar*	*Camera*	*DSRC*	*CV+AV*
Object detection	Good	Good	Good	Fair	n/a	Good
Object classification	Good	Poor	Fair	Good	n/a	Good
Distance estimation	Fair	Good	Good	Fair	Good	Good
Edge detection	Good	Poor	Good	Good	n/a	Good
Lane tracking	Good	Poor	Poor	Good	n/a	Good
Visibility range	Good	Good	Fair	Fair	Good	Good
Poor weather performance	Fair	Good	Fair	Poor	Good	Good
Dark or low illumination performance	Poor	Good	Good	Fair	n/a	Good
Ability to communicate with other traffic and infrastructure	Poor	n/a	n/a	n/a	Good	Good

Figure 2. Comparison of sensing capabilities of human drivers and sensors in highly automated vehicles (Source: SWT-2017-12, University of Michigan)

CV : connected vehicle
AV :autonomous vehicle
CAV : connected autonomous vehicle
DSRC : dedicated short-range communications (wifi)

DSRC: wireless technology that can potentially meet the extremely short latency requirement for AV