Range sensors and range data

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Lecture outline

- Available 3D sensing methods; illustration on a self-driving car
- Time of flight sensors
- LiDAR = Light Detecting And Ranging
- RADAR = Radio Detecting And Ranging
- Sonar, originally an acronym for sound navigation ranging
- Most common and cheap 3D sensor = Microsoft’s KINECT (and its variants by other manufacturers)

Courtesy: EU funded UP-Drive project; presentations and texts of many colleagues from web

Existing 3D Sensing Methods

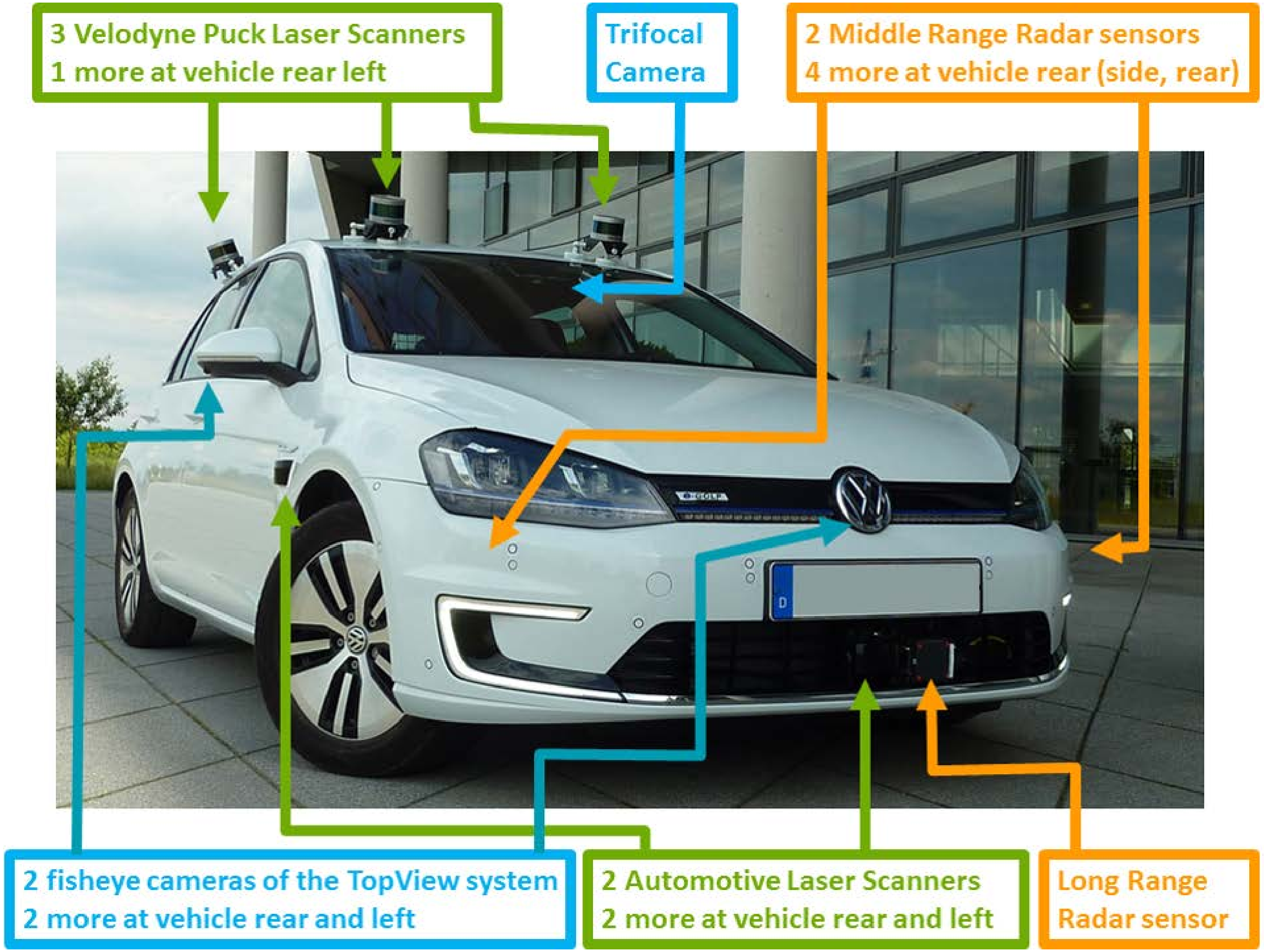
- Time of flight
  - LiDAR, RADAR, sonar, shuttered light pulse
- Triangulation
  - Laser stripe scanner
  - Stereo
  - Structured Light
    - Can be implemented with commercial cameras and projectors
    - Sinusoids / Moiré gratings (Takeda and Kitoh; Tang and Hung, Sansoni *et al*)
    - Stripe patterns (Koninckx, Griesser, and Van Gool; Zhang, Curless, and Seitz; Caspi, Kiryati, and Shamir; Liu, Mu, and Fang)

Motivation, an experimental self-driving car

UP-Drive project experimental car, VW e-Golf

Combine the sensing technologies:

- LiDAR
- camera
- RADAR



Computers dealing with self-driving

Front LiDAR and RADAR

LiDAR

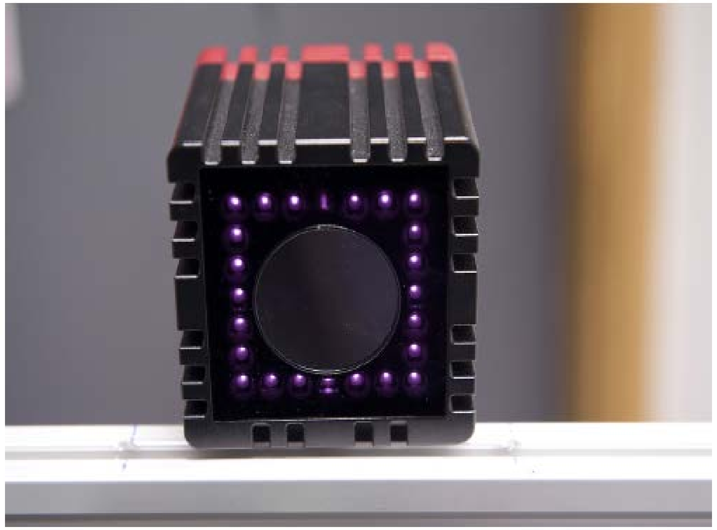
Long range RADAR

Side LiDAR and two 60° cameras

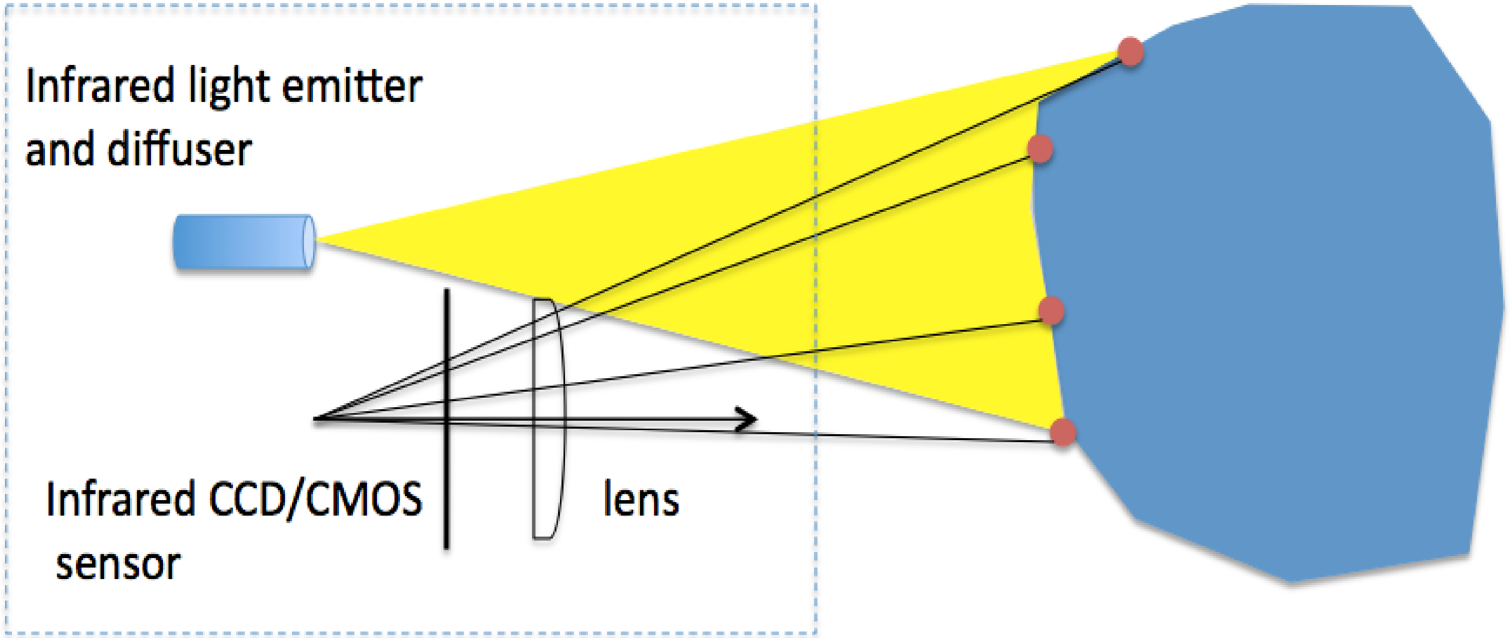
Front camera

camera

Time of flight (TOF) sensor



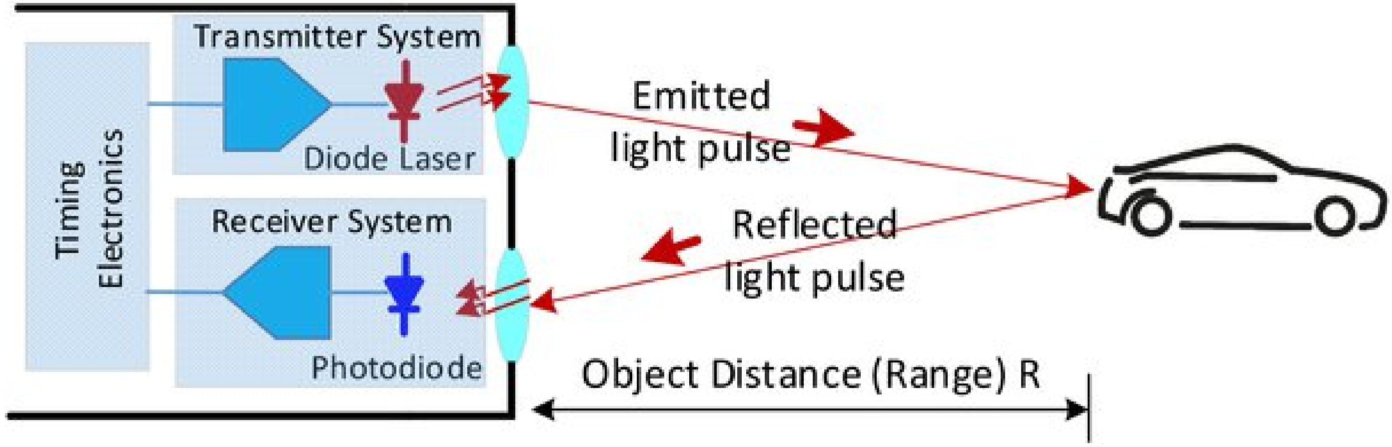
http://www.mesa-imaging.ch/

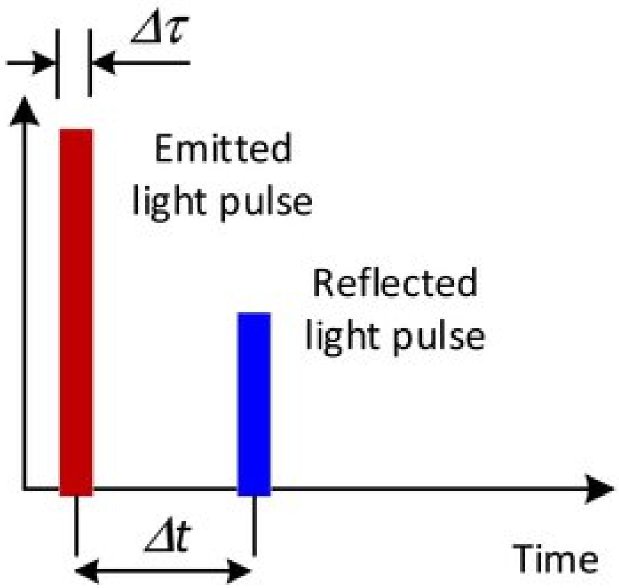


Time-of-flight camera

- Continuous wave modulation: The phase difference between the sent and received signals is measured.
- The modulation frequency is in the range 10 to 100 MHz.

The principle of 3D flash sensor (LiDAR)





Scanning LiDAR

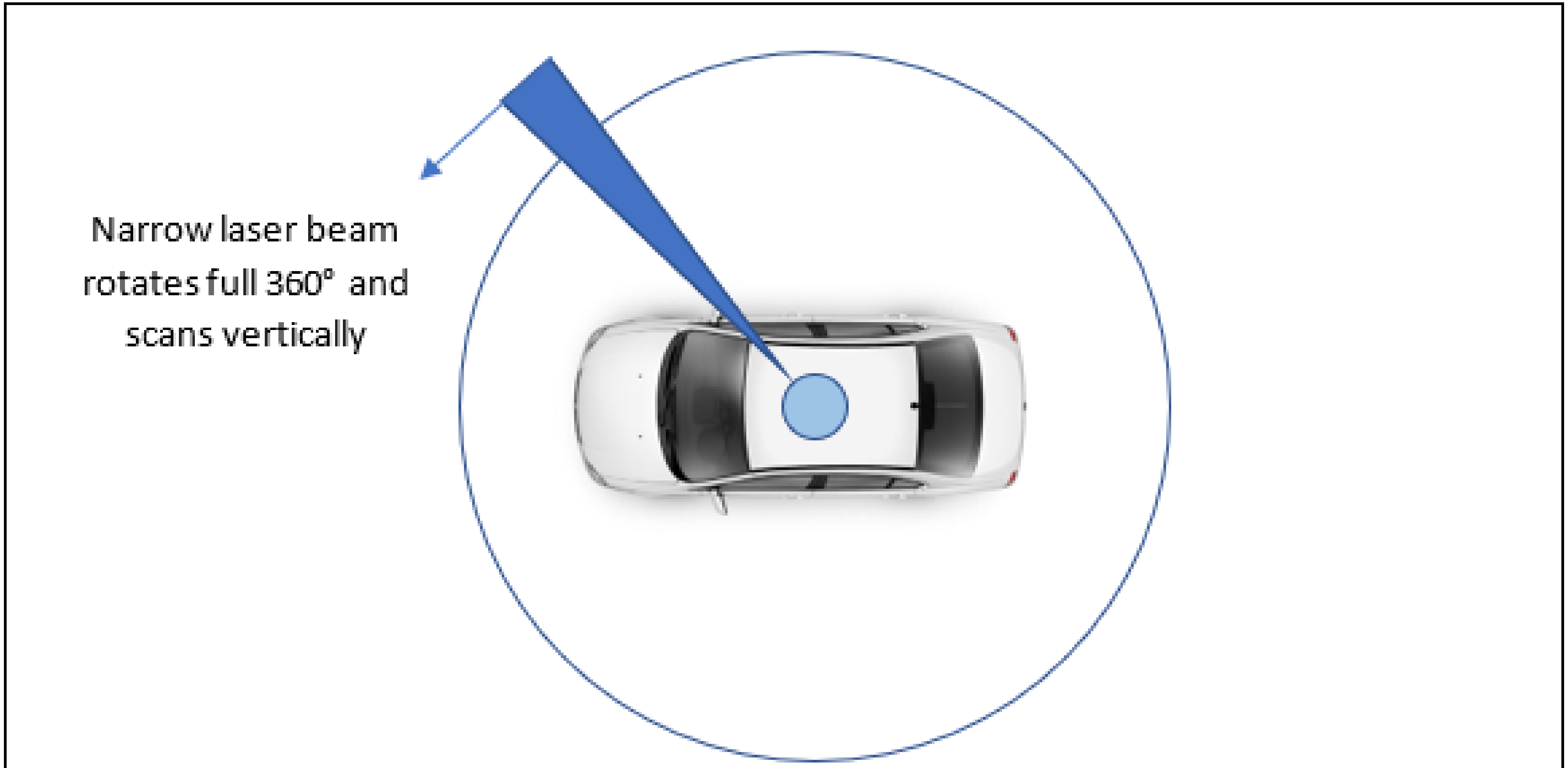


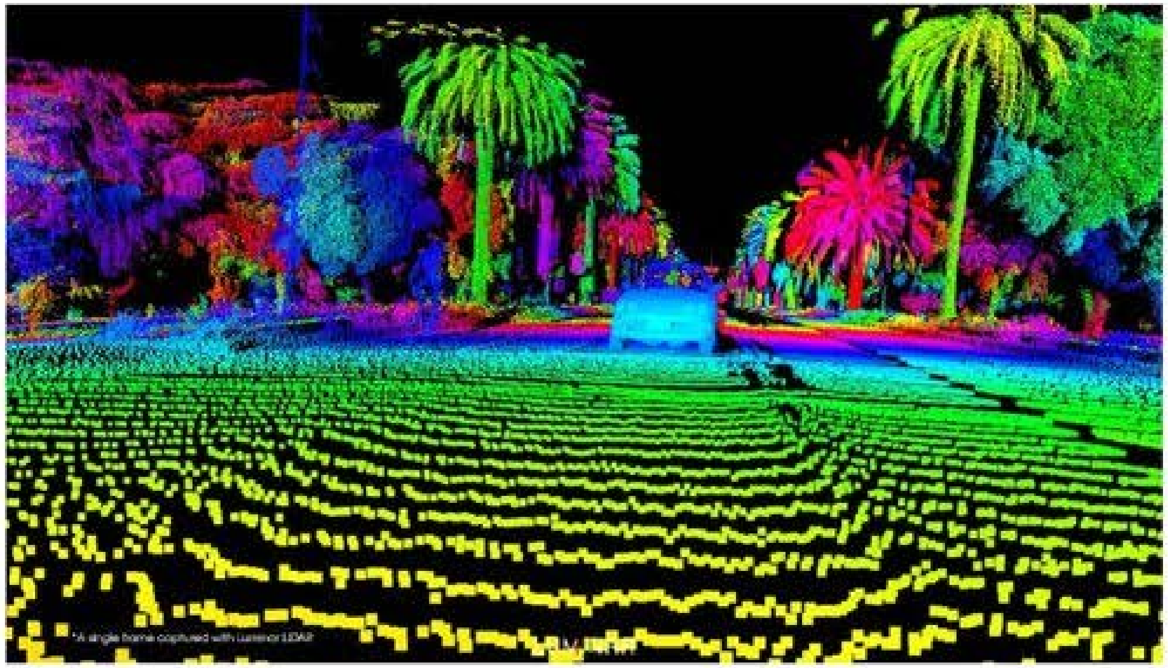
Figure 2. Scanning Lidar

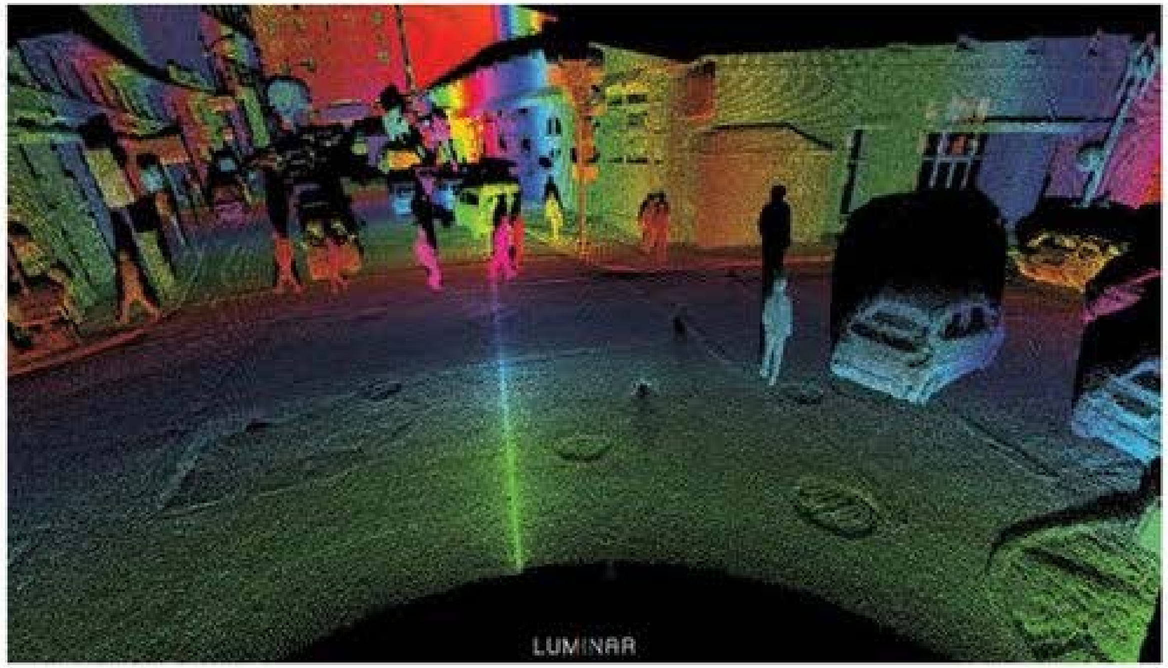
LiDARs, examples from different manufacturers

(a) (b) (c) (d) (e)

Velodyne’s 360°, 905 nm spinning lidar with 16, 64 and 128 lasers respectively) (a), (b) and (c); Luminar’s 1550 nm, 200 m range macroscopic scanning mirror lidar (d); and Ouster’s OS-1 850 nm flash lidar/CMOS camera (e)

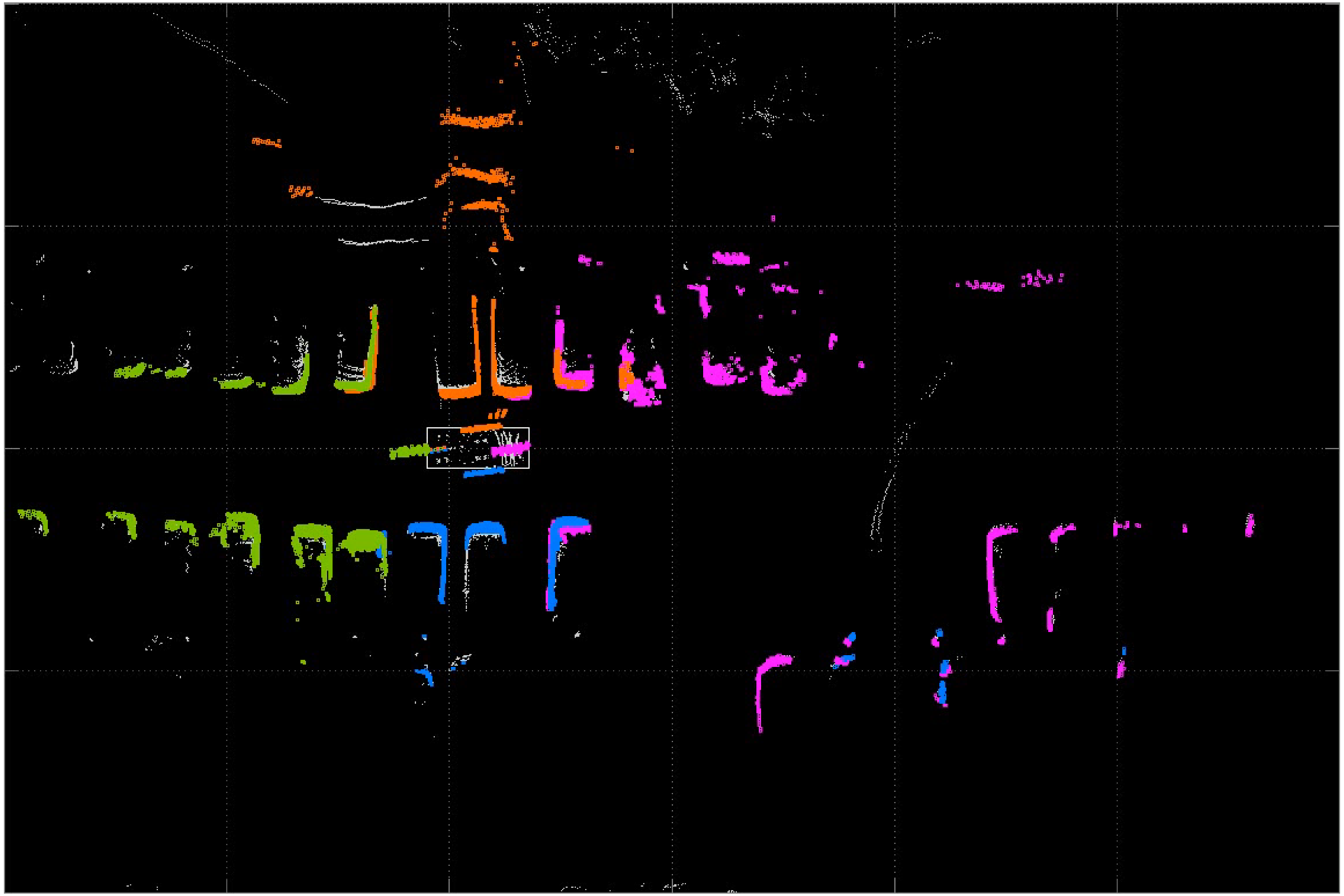
Luminar’s LiDAR images





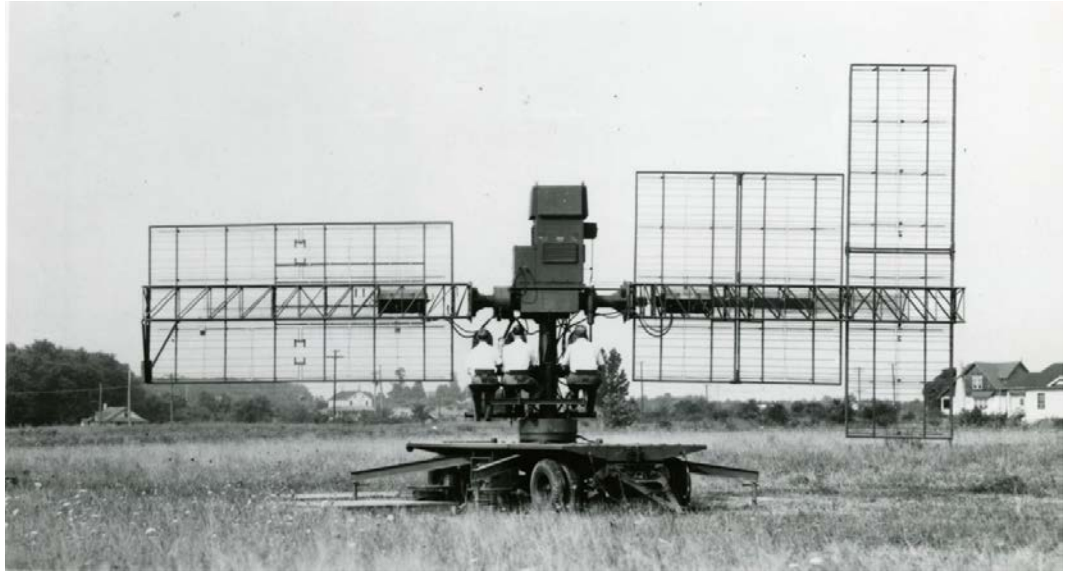
Single frame images produced by Luminar’s LIDAR sensor (Courtesy of Luminar)

LiDAR, the video from VW experimental car



RADAR = Radio Detection and Ranging

- Emits radio waves, part of which get reflected from objects.
- The time it takes for sound to travel forward and backward is determined by the distance of the sound source and the surface that reflects.
- Similar for SONAR, which uses (ultra)sound waves.



The SCR-268, the first aircraft detection radar in the United States. It entered service in 1940.

RADAR use in self-driving car

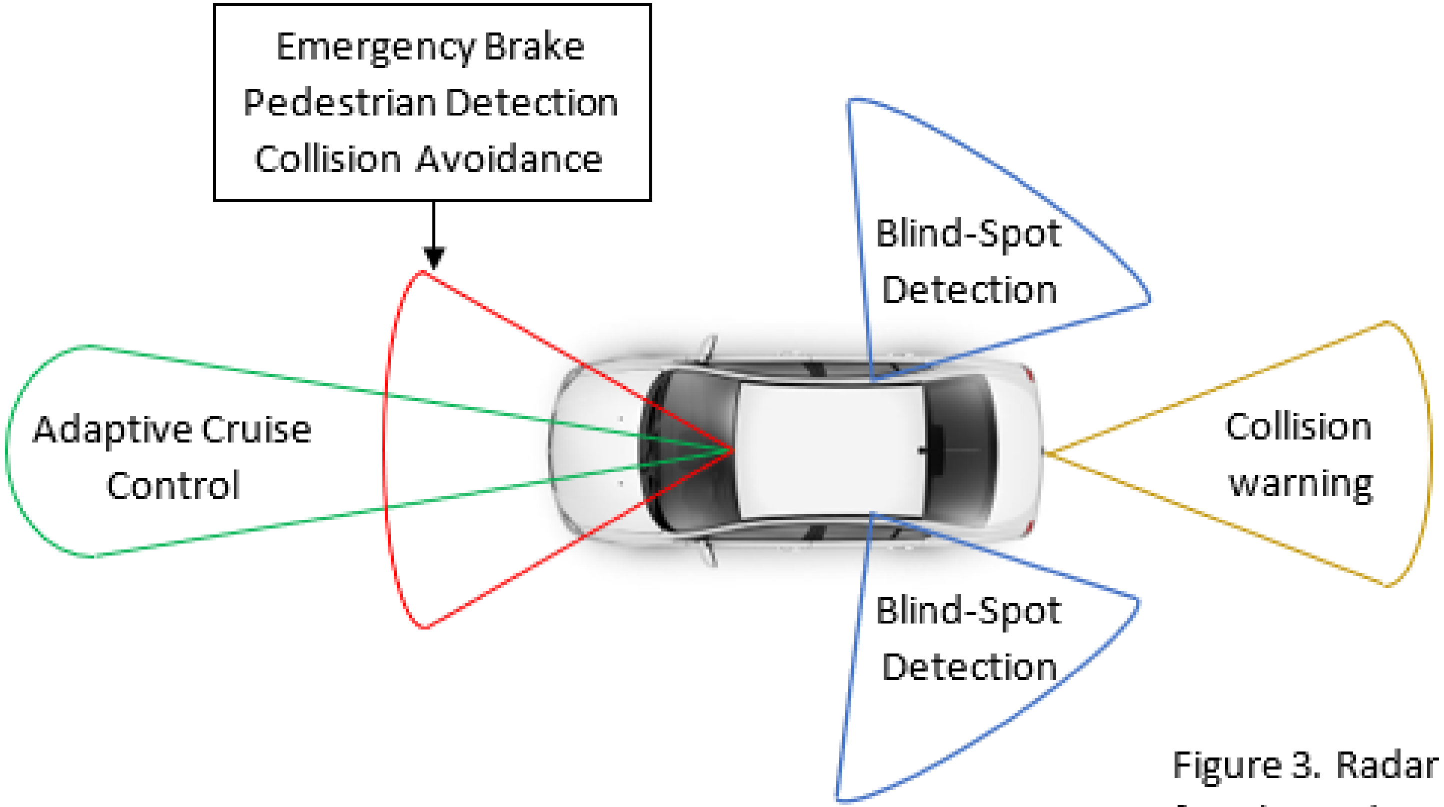
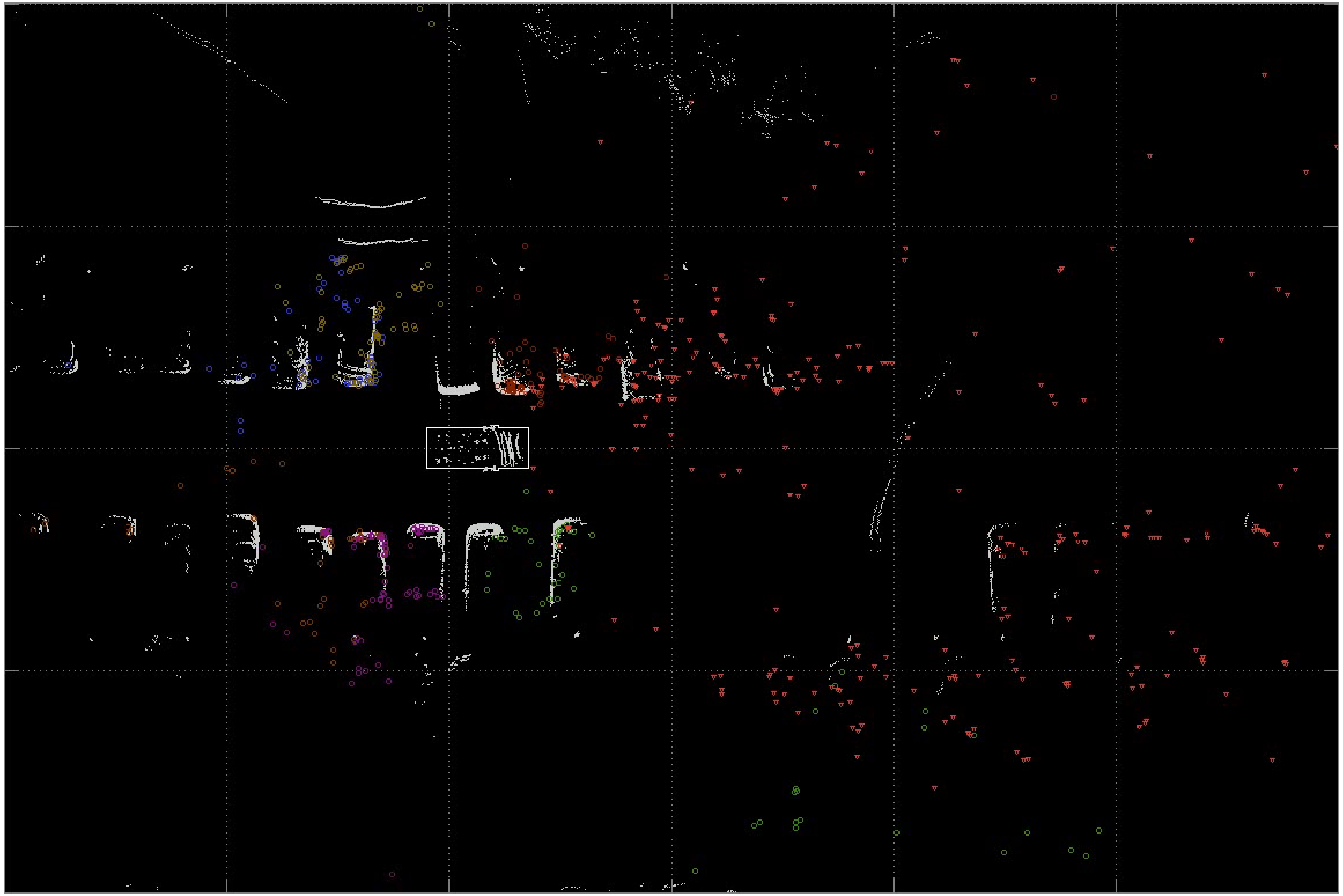
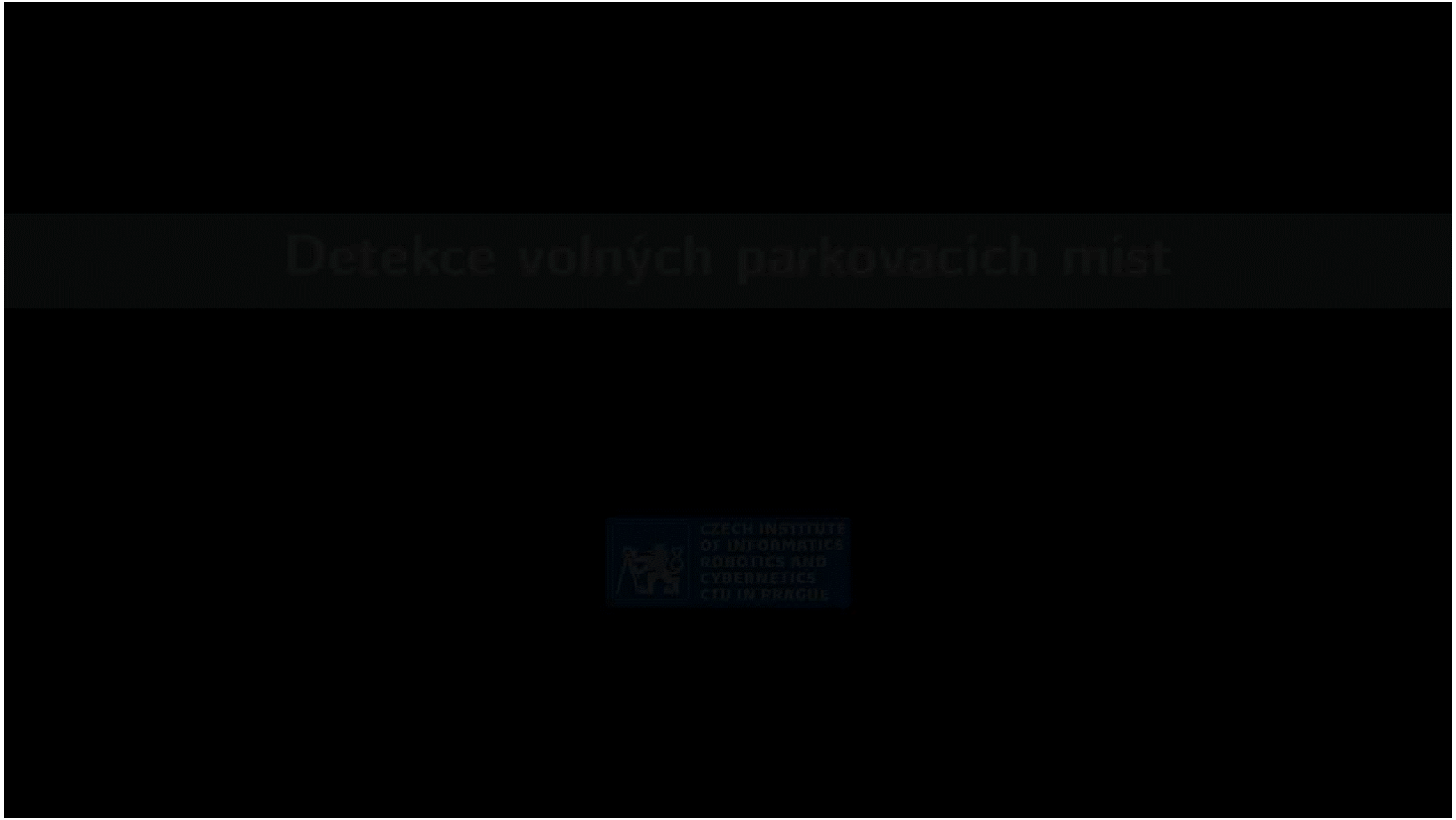


Figure 3. Radar systems for object detection and collision avoidance

RADAR, the video from VW experimental car



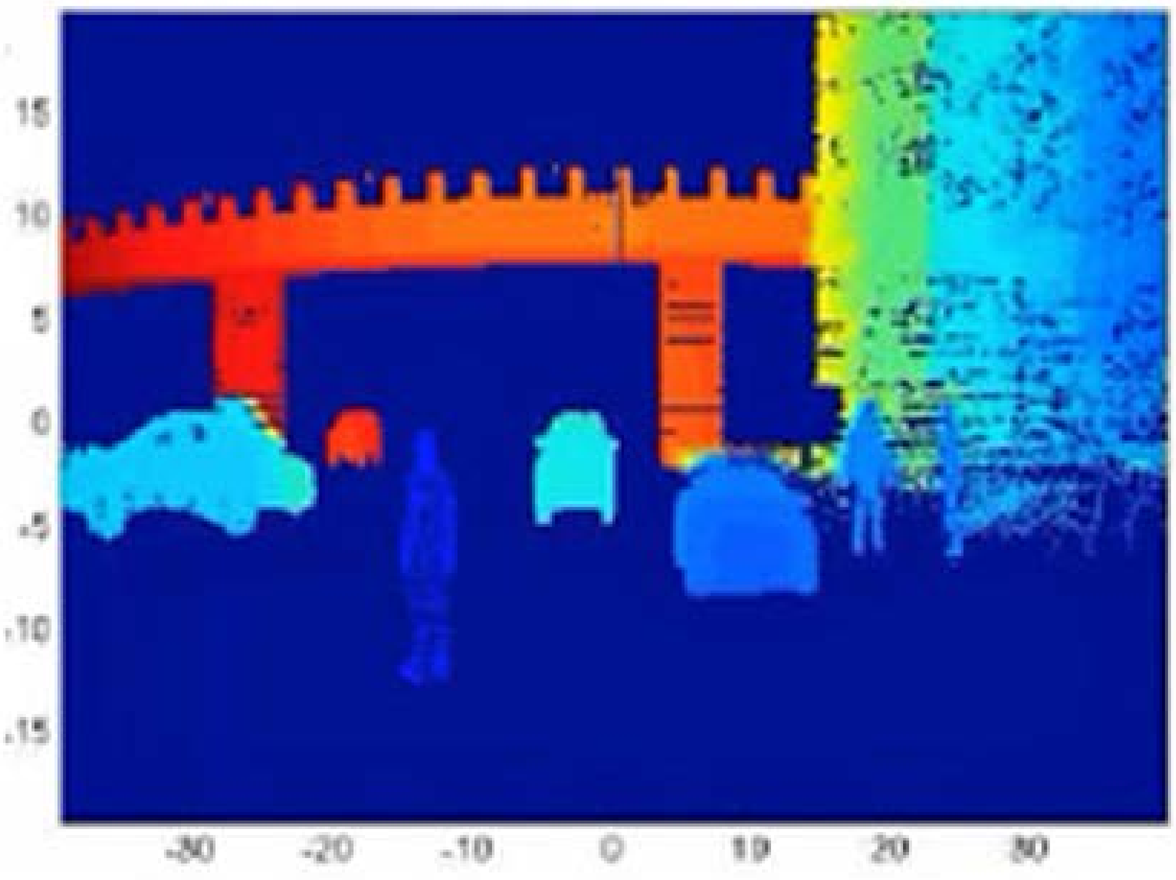
UP-Drive project, parking spot detection



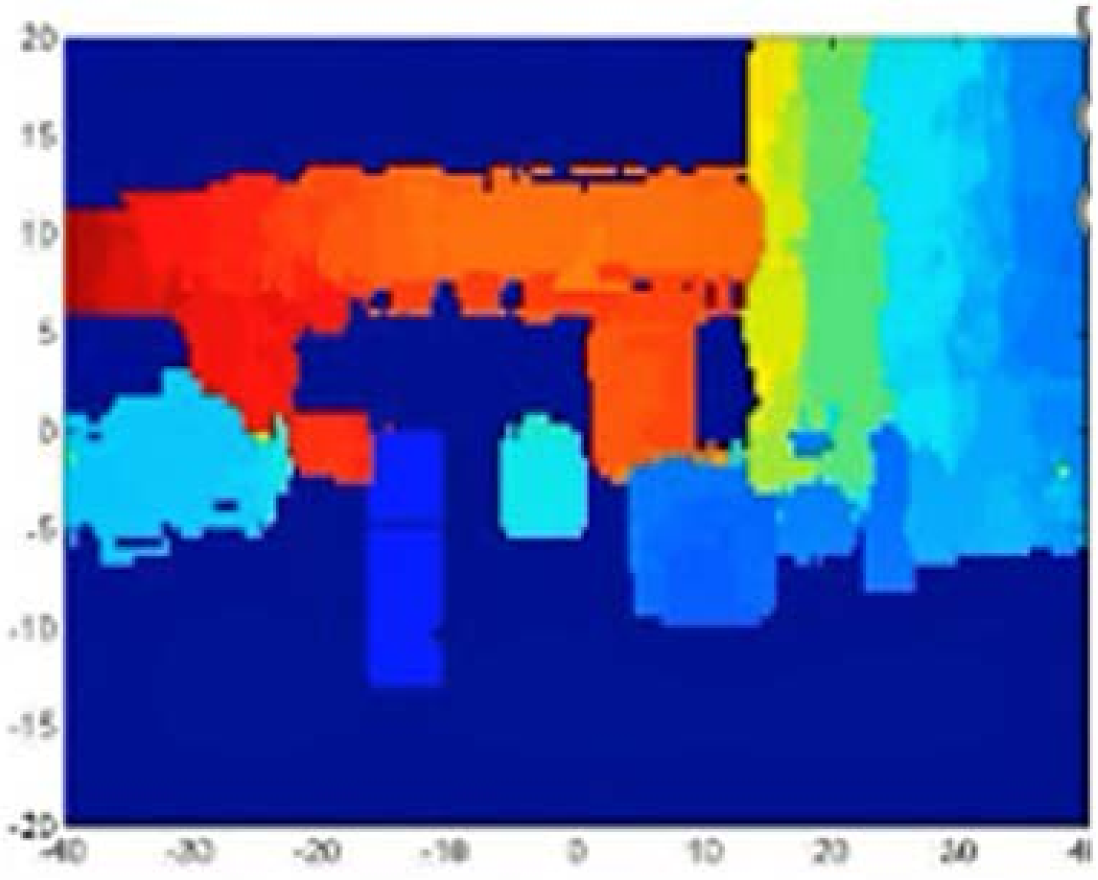
RADAR vs. LiDAR

- Advantages of RADAR over LiDAR
  - RADAR can easily operate in cloudy weather conditions, and at night.
  - Longer operating distance.
  - RADAR can determine moving object velocity using Doppler frequency shift.
- Disadvantages of RADAR usage
  - Longer wavelength does not allow the detection of small objects.
  - RADAR cannot provide the user with the precise image of an object because of the longer wavelength.
- Advantages of LiDAR over RADAR
  - Short wavelength lets us detect small objects.
  - A LIDAR can build an exact 3D monochromatic image of an object.
- Disadvantages of LiDAR usage
  - Limited usage in nighttime/cloudy weather.

LiDAR vs. RADAR



Lidar

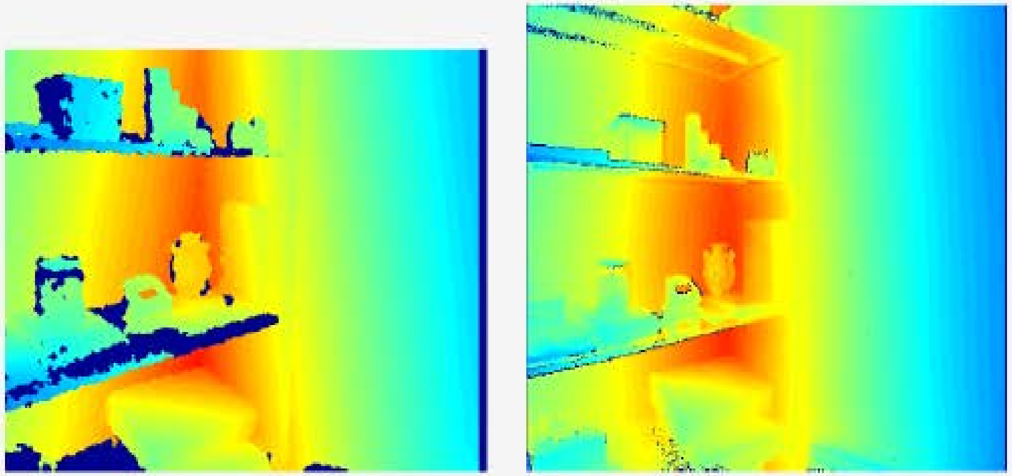


High Resolution Radar

Kinect v1 and v2, probably the most popular depth sensor

Kinect v1 : based on triangulation

Kinect v2 : based on time of flight



(a) Kinect v1 (b) Kinect v2

Fig. 2. Captured depth images of the same scene for the Kinect v1 and Kinect v2.

	Kinect v1		Kinect v2	
	Resolution [Pixel × Pixel]	Frame Rate [Hz]	Resolution [Pixel × Pixel]	Frame Rate [Hz]
color	640 × 480	30	1920 × 1080	30
depth	640 × 480	30	512 × 424	30
infrared	640 × 480	30	512 × 424	30

Table 1. Resolution and frame rate of the images captured by a Microsoft Kinect v1 and Kinect v2.

Comparing stereo, structured light and TOF

CONSIDERATIONS	STEREO VISION	STRUCTURED-LIGHT	TIME-OF-FLIGHT (TOF)
Software Complexity	High	Medium	Low
Material Cost	Low	High	Medium
Compactness	Low	High	Low
Response Time	Medium	Slow	Fast
Depth Accuracy	Low	High	Medium
Low-Light Performance	Weak	Good	Good
Bright-Light Performance	Good	Weak	Good
Power Consumption	Low	Medium	Scalable
Range	Limited	Scalable	Scalable
APPLICATIONS			
Game		X	X
3D Movies	X		
3D Scanning		X	X
User Interface Control			X
Augmented Reality	X		X

Source: https://eu.mouser.com/applications/time-of-flight-robotics/