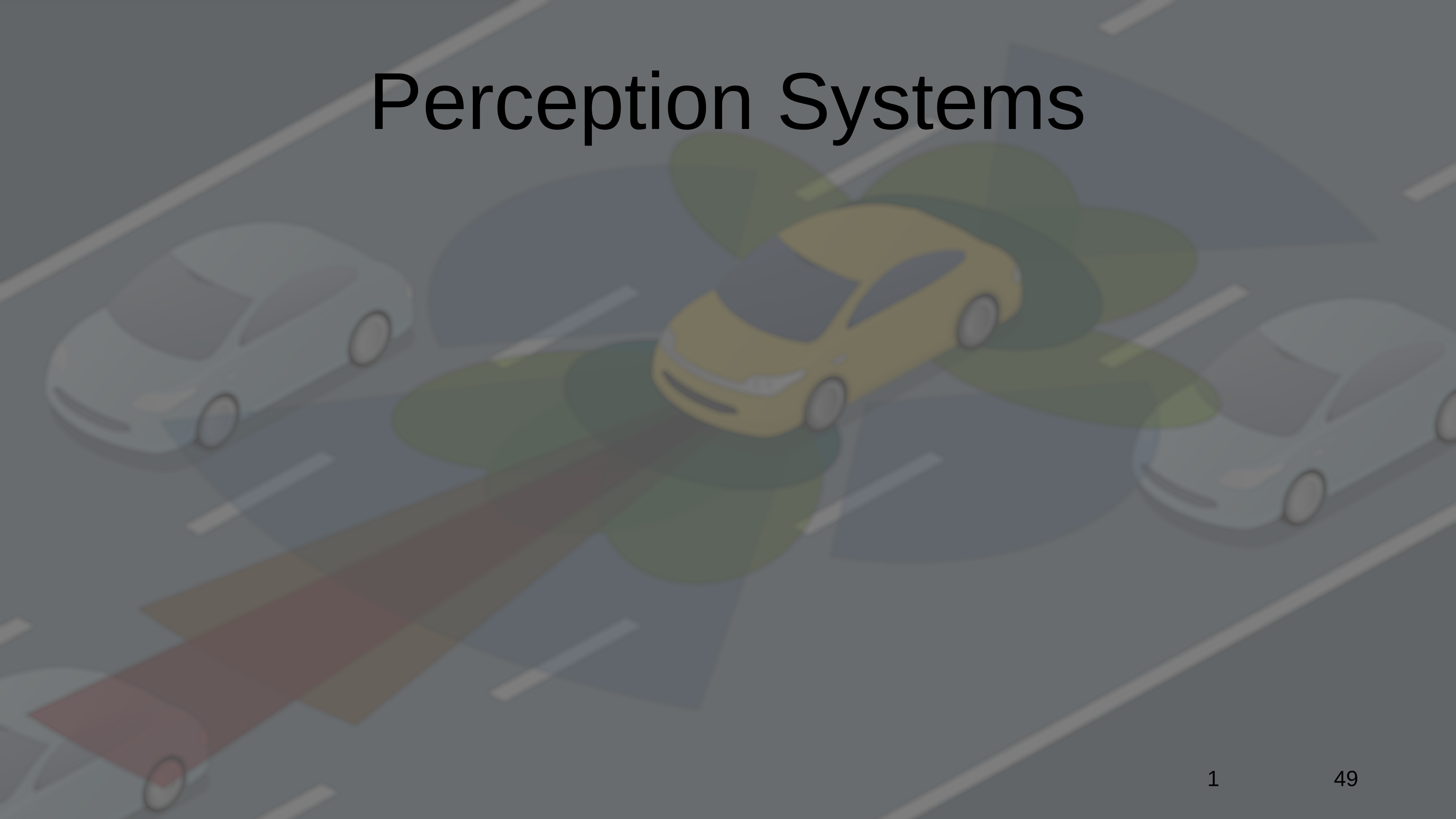
Perception Systems



You should be able to:

- List which perception systems are used in ADAS.
- Explain theory and operation of Camera (optical, thermal, infrared), SONAR ,RADAR, and different types of LIDAR used with ADAS.
- Describe how these sensors work together to greatly enhance ADAS/Autonomy systems and operation.

Terms to know.

- Acoustic impedance.
- CCD (Charge Coupled Device)
- Doppler Radar/Doppler effect.
- LIDAR.
- FLIR (Forward Looking Infrared).
- MEMS (MicroElectroMechanical Systems.
- FMCW (Frequency Modulated Continuous Wave).

More terms to know.

- OPA (Optical Phased array).
- SEDAR (Spectrum Enhanced Detection and Ranging).
- Stereo Camera.

The purpose of perception systems.

- These systems are designed to help minimize the consequences of distracted driving.
  - They do this by replicating and enhancing the spatial awareness we, as humans, possess.
- These systems, using various sensors and technologies, can basically have a 360 degree uninterrupted field of view around the vehicle.

Perception System Components.

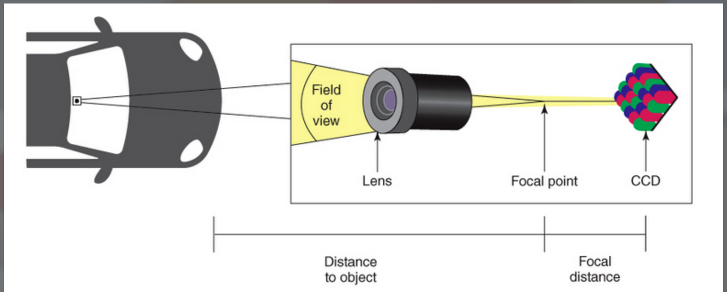
- Cameras.
  - Many different camera functions are incorporated.
    - By using different cameras, having one camera perform different functions, or combining the output from different cameras.
      - Examples: Lane departure warning, lane keeping assistance, lane change assistance, traffic sign recognition, adaptive cruise control, front cross traffic alert, pedestrian/animal classification, night vision, parking assistance, mapping assistance, collision avoidance and mitigation, intelligent headlight control and maybe others.

Camera theory and operation.

- A camera contains one or more lenses which may be fix-focus or focus able.
  - A small, possibly variable, opening through which the captured image or light travels.
  - A device that will convert the received light or image in to electrical signals.
    - The actual sensor is likely to be a CCD (Charge Coupled Device) because they have very good performance.
      - These sensors require a fair amount of power and are expensive, so CMOS may be used instead.

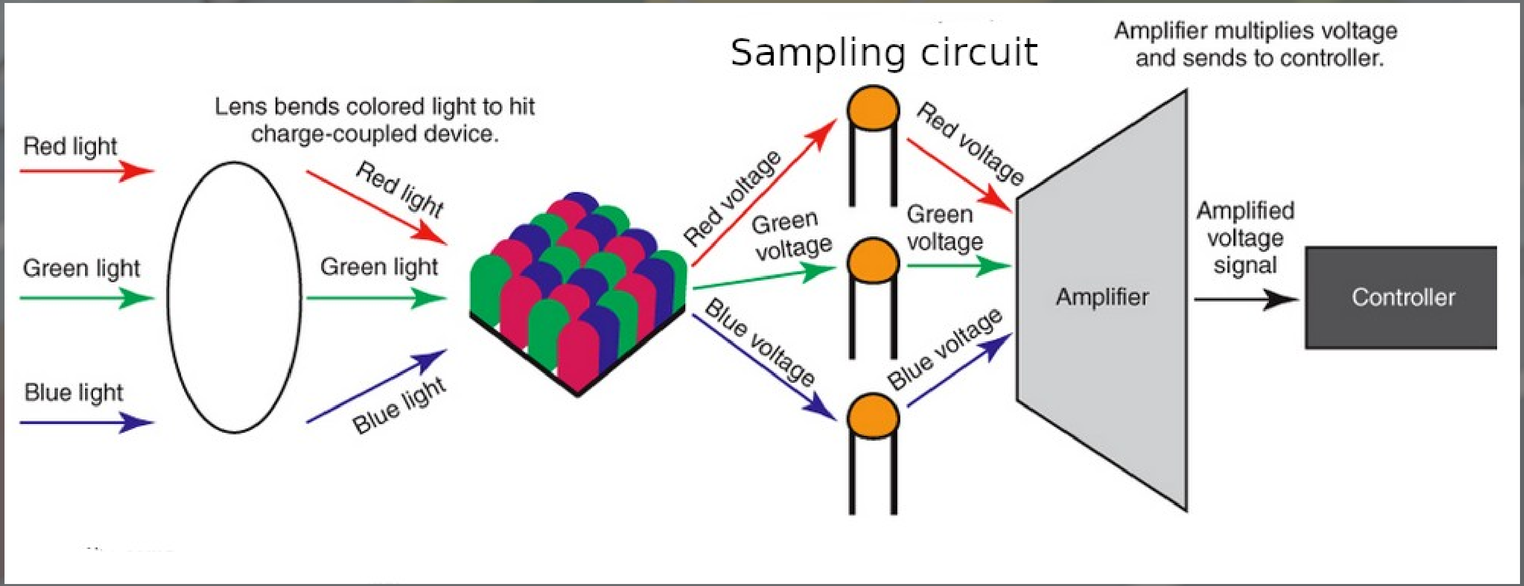
Camera theory and operation (cont).

- These camera sensors are optimized to see better in the dark than we do and may not have a full color view.
  - Due to the optimization they may use a white light sensor instead of a green color sensor (RWB instead of RGB)



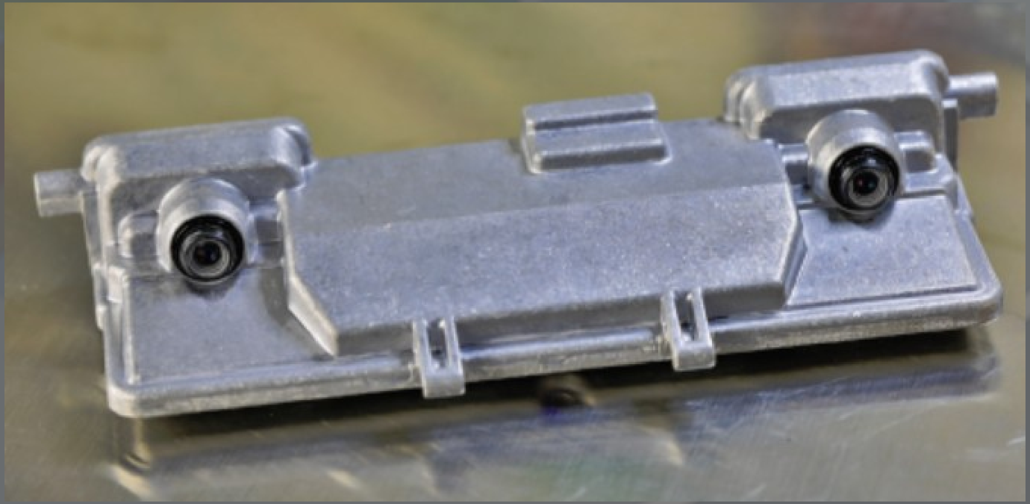
Camera theory and operation (cont)

- CCD operation. Presently about 8MP resolution at 60 FPS.-Continually evolving and improving.



Camera theory and operation (cont)

- Many manufacturers use two cameras in the same plane or module, called a stereo camera.
  - A stereo camera allows accurate depth (distance) perception.



Camera usage.

- By sampling or taking multiple images in succession the processors can determine direction of travel and speed and will determine the vehicle’s trajectory.
- The system will then predict where the vehicle will be the next point in time.
  - This prediction is dynamic and continually updated.

Why accurate alignment?.

- If the camera is not aligned properly there is a possibility that a wrong or inaccurate corrective action will be taken when one is needed.
  - One example may be placement in lane where a camera out of calibration may cause the vehicle to be too far to the right or left in the lane.

Recognizing objects.

- Onboard and sometimes offboard processing is used for object classification.
  - One example is neural networks used for the systems to learn about objects.
    - COCO (Common Objects in COntext)
    - Pose detection. (Human or animal, moving or not, intention) Is action needed or not?
    - Semantic detection. (Roads, bridges, lanes, barriers etc)

Used in a system.

- Most commonly the output from a camera system, equipped with a neural network or not, will be fed to a master controller.
  - The master controller will have inputs from other systems and so will be better equipped to decide what the ADAS/Autonomous system should do.
    - Evasive action, stop, drive, slow down, etc.

Obvious disadvantages.

- Too dark.
- Too light.
- Snow.
- Heavy rain.
- Fog.
- Lane markings.

Radar

- RAdio Detection And Ranging
  - Types:
    - SRR (Short Range Radar)
    - MRR (Mid Range Radar)
    - LRR (Long Range Radar)

Radar (cont)

- SRR
  - Blind spot detection.
  - Lane change assistance.
  - Cross traffic alert.
  - Parking assistance (automated parking).
  - Rear collision warning.
  - Range is about 30 meters or 100 feet or so.

Radar (cont)

- MRR
  - Adaptive cruise control.
  - Emergency braking.
    - Range is about 150 meters or 500 feet or so.

Radar (cont)

- LRR
  - Adaptive cruise control.
  - Emergency braking.
    - Range is roughly 200 meters or 650 or so feet.

Radar theory and function

- The system is comprised of a transmitter, sometimes called an emitter, and a receiver.
  - The system sends out a radio wave.
    - The frequency is quite high, in the 76 to 81 GHz range.
      - So the wavelength is only 3-4 cm (1.5-1 in, which is why these frequencies are called centimeter (or millimeter) waves.
        - Since the wavelength is so short, we can get away with using very small and compact antennas.

Radar theory and function (cont).

- The radio energy sent out will bounce off of objects encountered.
  - The strength of the returned echo depends on something called the radar cross section of the object. -Most objects will return a relatively strong echo.
  - Due to the high frequency used and DSP (Digital Signal Processing) these radars can resolve objects down to 5 cm or about 2 inches in size.

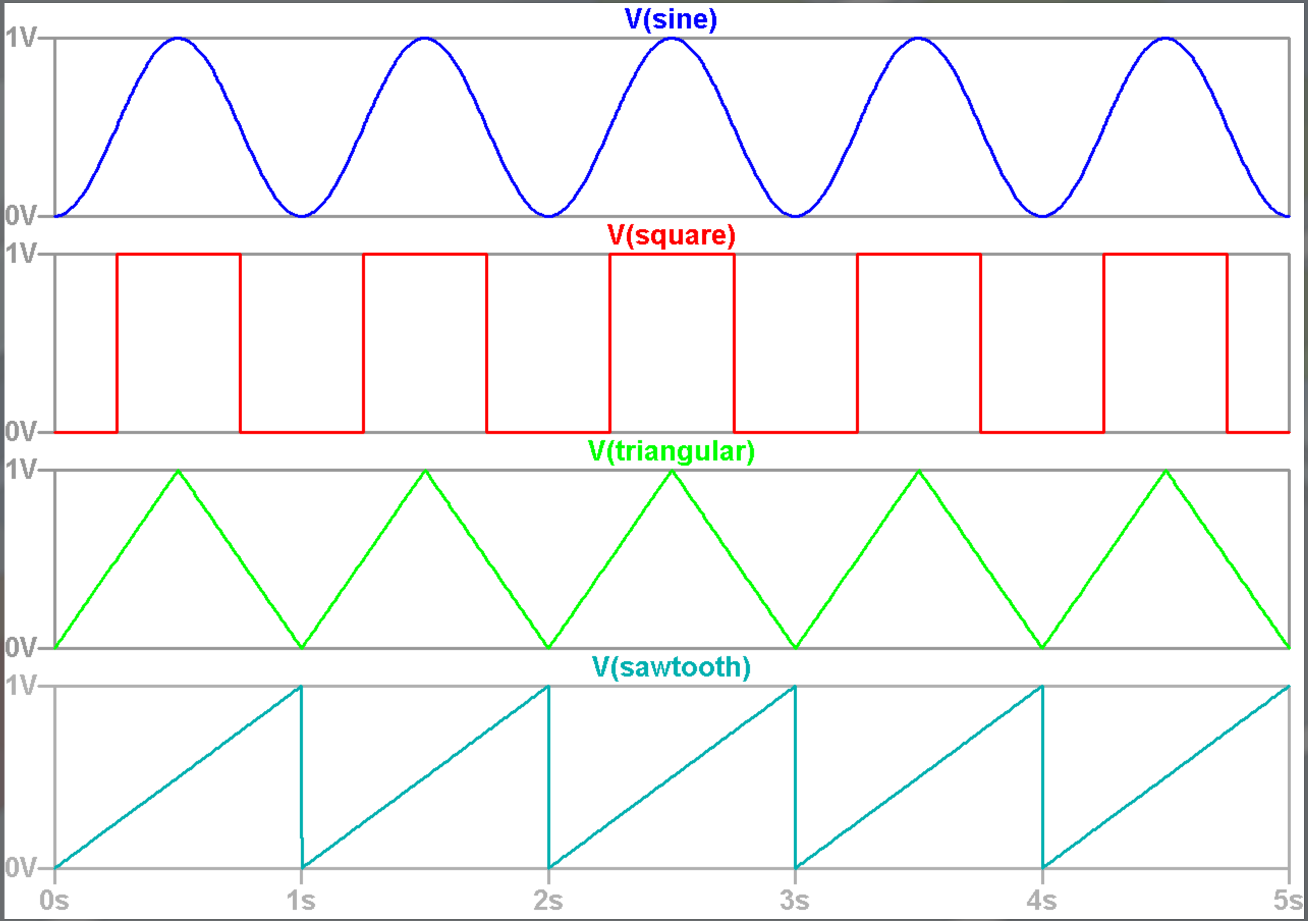
Radar theory and function (cont).

- These radars are not pulsed as earlier types, but emit CW (Continuous Wave).
  - The wave is “chirped” or changed (modulated) in such a way that the distance and direction to the echoing object can be determined.
    - There are several ways that the chirping is accomplished, but all of them changes the emitted frequency in some manner.
      - Triangle,saw tooth, sine. (Square wave is unlikely since only two states can exist.)

Radar theory and function (cont)

- Since the frequency of the transmitted wave is changed (chirped) it is possible to “see” or resolve small objects.
  - This is done by sending the received signal through delay lines and allowing the received signal to “stack”.

Radar theory and function (cont).



Radar theory and function (cont).

- The radar calculates distance by measuring the time between the sent and the received signal.
  - Divided by 2 since the measured time is back and forth.
    - So time is time between sent wave and received wave divide by 2.
      - (time*velocity)/2
        - Velocity is the speed of light (186,000 m/s)
          - Time will be a very small value, depending on the distance.

Radar theory and function (cont)

- The central control unit will decide what corrective, if any, action to take.
  - The decision will be based on distance, velocity, location, etc.
    - Velocity is based on the Doppler phenomenon.

Radar theory and function (cont)

- Doppler?
  - The received frequency of the echo will be frequency-shifted.
    - Either increasing or decreasing frequency.
      - Depending on if the object giving the echo is moving away or approaching.
        - The amount of frequency-shift depends on the object’s relative velocity compared to your velocity.
          - So, the speed differential.

Radar theory and operation (cont)

- If you have ever paid attention to the sound of an object coming towards you at speed, you have experienced the Doppler shift.
  - Ambulances, police cars, trains, etc.
    - Sound increasing in pitch as they approach you and decreasing as they leave you.

Radar theory and application (cont)

- Doppler effect.
  - With radar, the wave travels at the speed of light, not the speed of sound, so the calculations are a little different.
    - Very simplified.
      - Frequency seen by the receiver = Frequency transmitted times roughly the speed of the object (plus or minus).

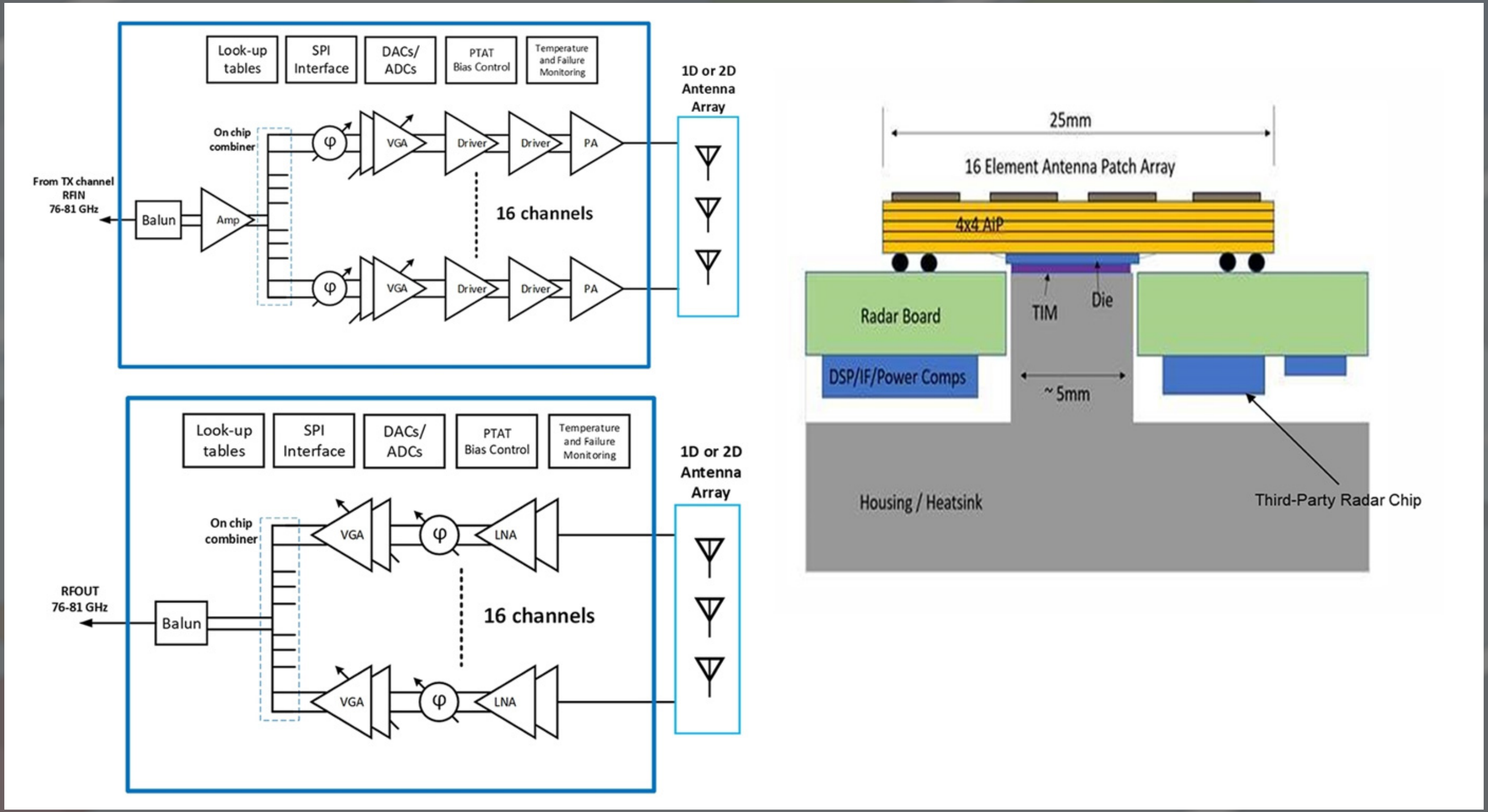
Radar theory and function (cont)

- The antennas for transmitting and receiving are co-located but in such a way that they do not interfere with each other.
  - This normally entails spacing the antennas exactly one half wave length apart so they “null” out.

Radar theory and function (cont)

- The transmitting (and receiving) antennas use “beam steering” to send the electromagnetic energy in the desired direction and to determine from where the echo is emanating.
  - Beam steering is accomplished by changing the relative phase, polarity, and amplitude of the transmitted radar energy. Receiver beam steering is done in a similar way by changing the sensitivity of the different receiving antenna elements.

Radar theory and function (cont).



Radar theory and application (cont)

- Some advantages and disadvantages of Radar.
  - +Radar will go through certain materials such as plastic and clothing. You can even see through some walls since drywall is permeable to radio energy.
  - +Works well in fog and is impervious to sunlight.
  - -will not work well or at all if the emitter/receiver is covered in snow, ice, or road salt.

Radar theory and application (cont)

- Mitigation of drawbacks:
  - The AV/ADAS system will use other sensors to overcome the disadvantages that radar has.

Sonar

- SOund Navigation And Ranging.
  - Uses ultrasound.
    - Has an emitter (transducer) and a receiver (microphone)
      - Automotive sensors usually use the same transducer for send and receive.
        - The frequency of the sound is high enough so it does not bother humans or animals-
          - The sound is sent out in pulses or bursts. Not continuously.

Sonar (cont)

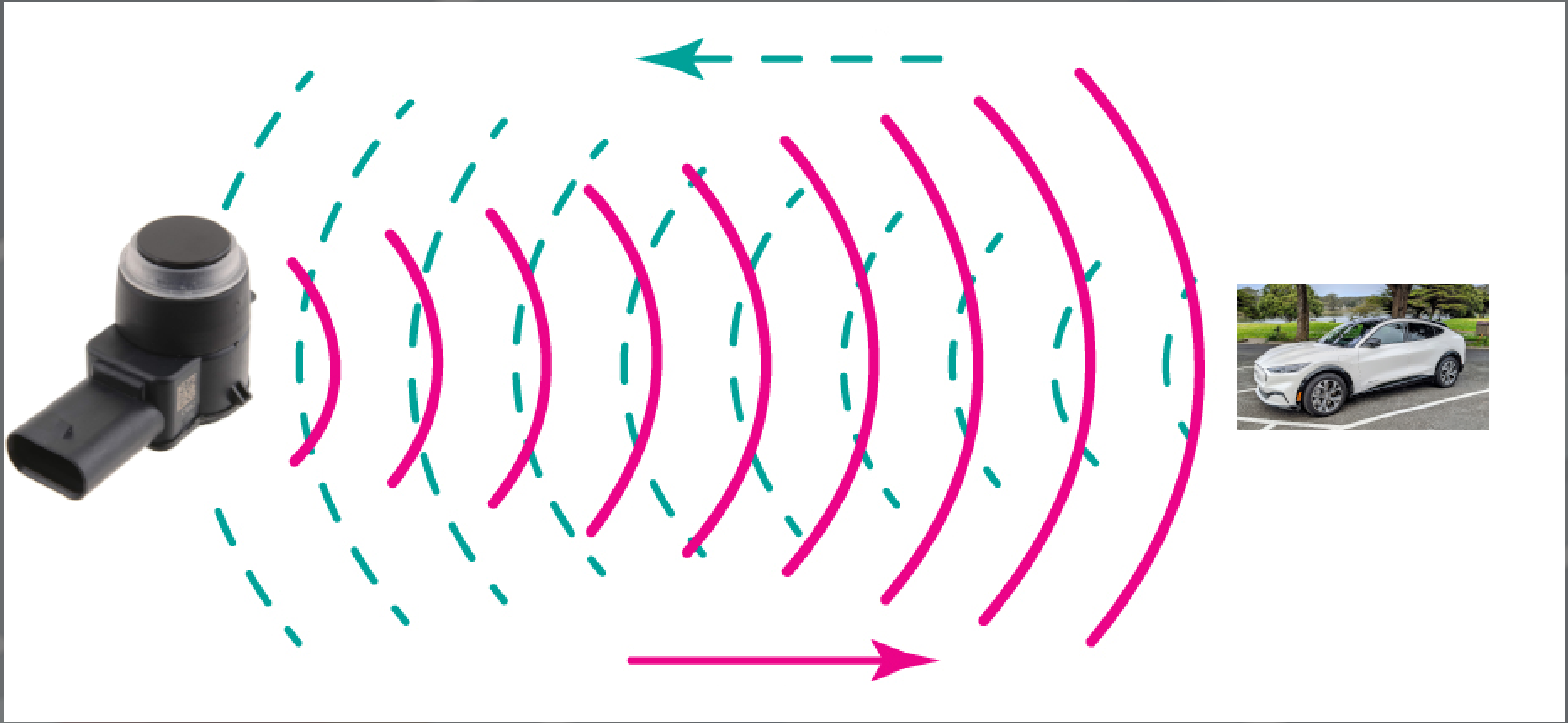
- The range is about 10 meters or 33 feet.
- The frequency is about 40 – 60 kHz.
- Since the same transducer is used for TX and RX, implementing velocity measurements using Doppler would be difficult, so not used.

Sonar (cont)

- Since the sensor operates by sound, it is subject to the same factors that affect any other sound wave.
  - Wave speed at 68F is about 343 m/s or 1125 f/s
    - The speed varies with air temperature, air pressure (altitude) and humidity. -Variable Acoustic Impedance.
      - The sound wave will rapidly disperse, hence the limited operating range, unless very high acoustical energy (power) is used.

Sonar (cont)

- The sensors may not need calibration, but may need to be programmed or registered to the vehicle.
  - The sensors are affected by paint thickness and other coating of the sensor. It may be best to purchase pre-painted sensors instead of repainting existing sensors.
    - The sensors are relatively inexpensive.



LIDAR

- Laser Imaging Detection And Ranging

Lidar (cont)

- As the name implies, uses a laser.
  - The laser is used to illuminate surrounding objects.
  - The laser beam is scanned or moved about to illuminate all objects around.
    - Moved in azimuth and elevation.
      - Mechanically (slow, expensive, not practical for vehicles)
      - Electronically. Present technology.

Lidar (cont)

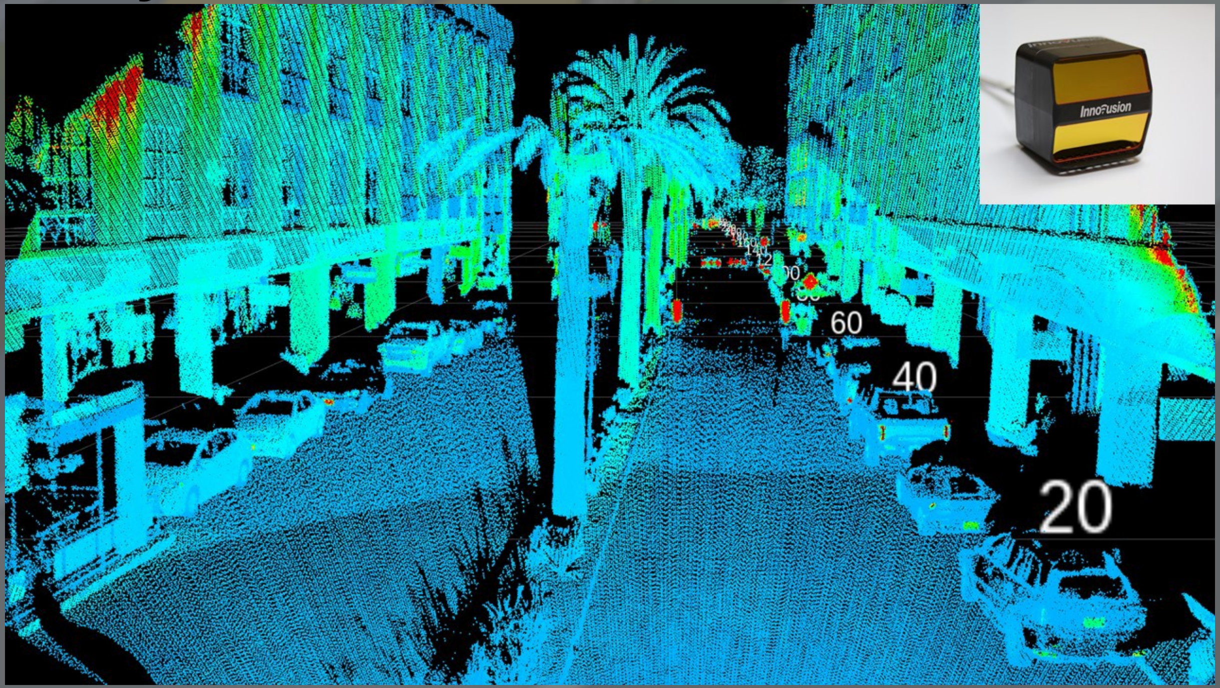
- The system receives and processes light reflected back as the laser beam hits targets.
  - Echoed light if you will.
    - Power must be limited so as to not damage the eyes of people and animals around.
      - This does limit the achievable range.
        - Certain color temperatures or wavelengths are more opaque to our eyes than others, so those are preferred.
          - However, wavelengths have a bearing on the effectiveness of the system, so a compromise.

Lidar (cont)

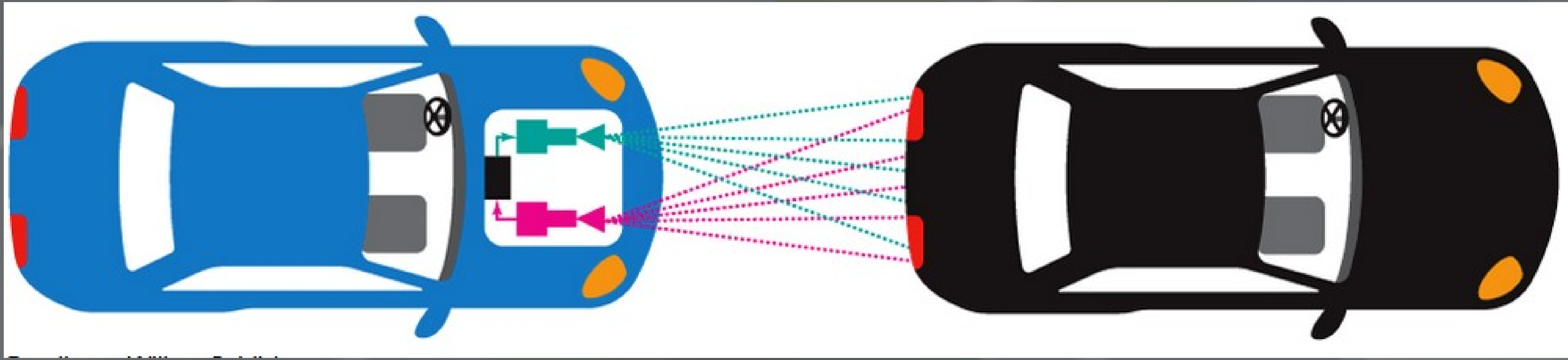
- Many Lidar systems use a pulsed laser and modulates the strength or amplitude (AM) of the beam, to determine distance and velocity.
  - This approach requires a lot of computing power and is sensitive to light sources such as sunlight and lighting flashes. The PRF (Pulse Repetition Frequency) is about 100,000 pulses per second.
- FM systems use a continuous beam that is frequency modulated (FM).

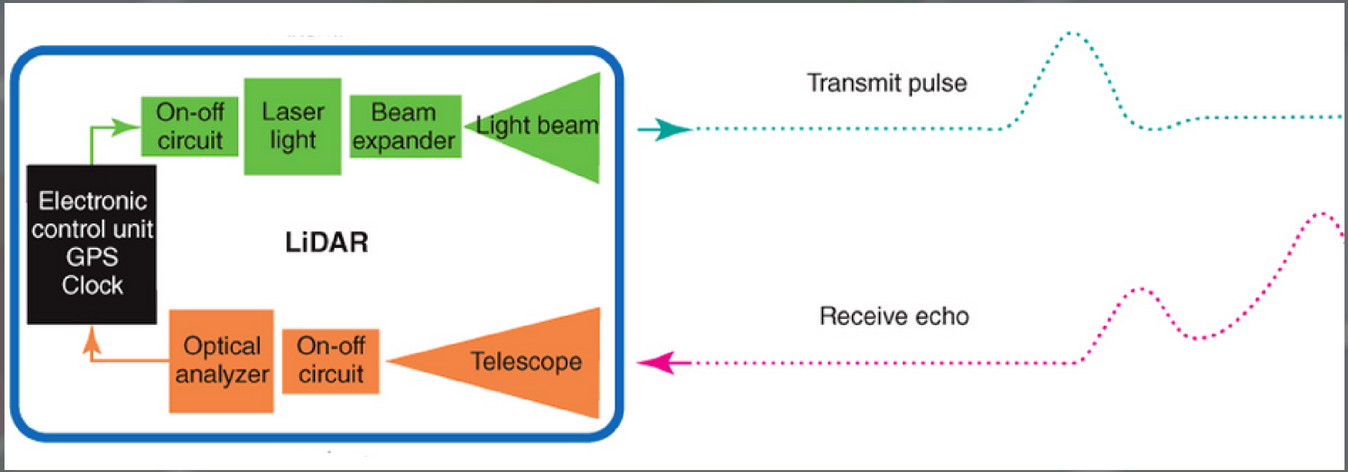
Lidar (cont)

- FM Lidar can more accurately determine distance and velocity and is also less sensitive to light sources.



Lidar (cont)




On-off
circuit
Laser
light
Beam
expander
Light beam
Transmit pulse
Electronic
control unit
GPS
Clock
LiDAR
Receive echo
Optical
analyzer
On-off
circuit
Telescope

Thermal and Infrared Cameras

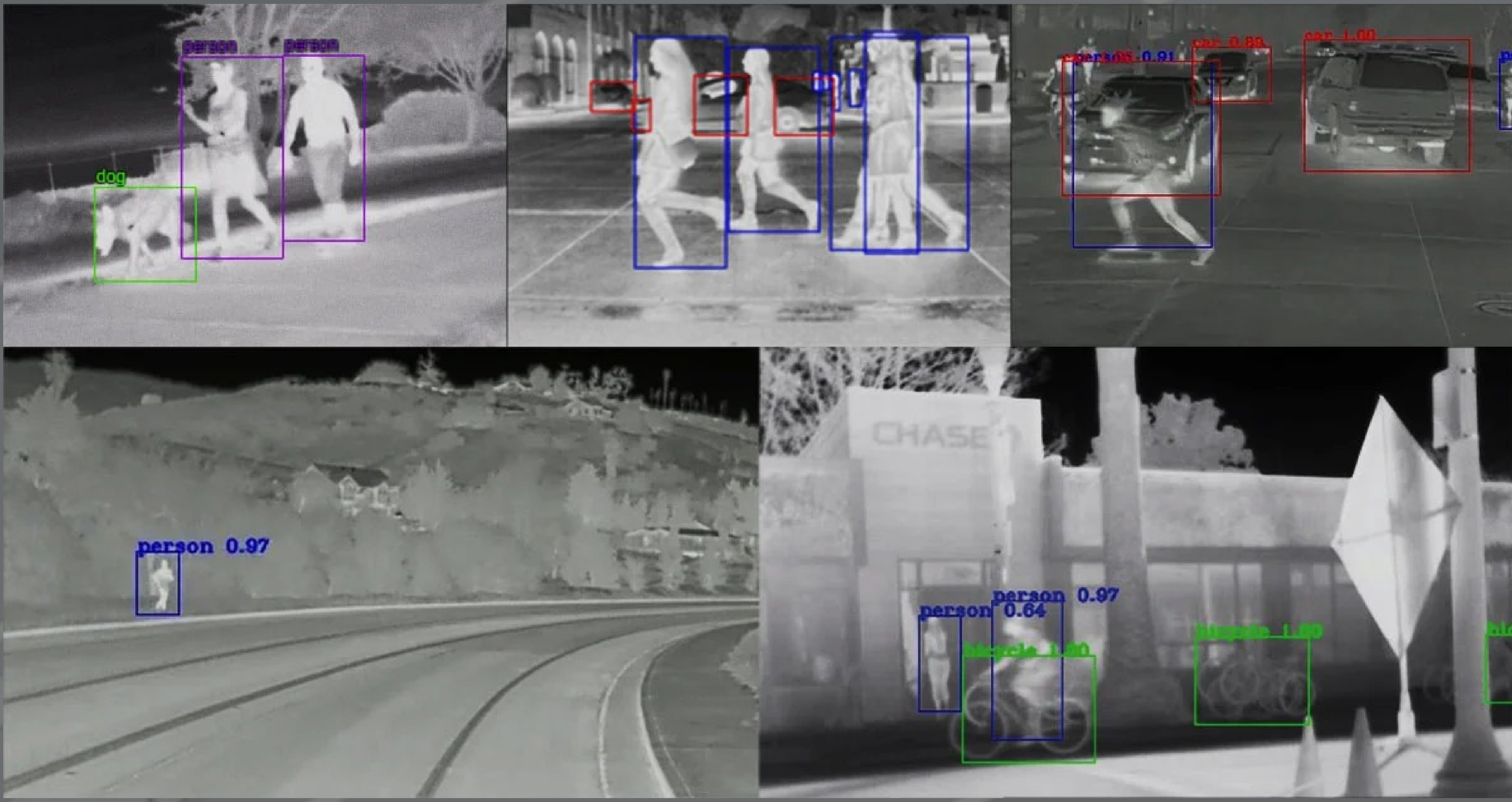
- NVS (Night Vision Systems) will utilize thermal or IR (InfraRed) cameras.
  - We call them cameras, technically they are sensors that are sensitive to heat or infrared radiation.
    - Earlier systems used thermal cameras. They have fairly poor resolution and so give few details (something is there, but what?).

Infrared cameras.

- Presently NVS systems use infrared sensors.
  - Commonly called FLIR (Forward-Looking InfraRed)
    - Main difference between a thermal and an infrared camera is that the thermal camera detects temperature differences from infrared radiation whereas an infrared camera captures the (very weak) infrared light given off by objects.
      - A FLIR camera will be sensitive to a fairly wide spectrum (0.7 to about 300 micrometers), much wider than a thermal camera.

FLIR

- The processing software will have algorithms designed to help with object classification.
  - What is the FLIR camera seeing?


person
person
dog
person 0.97
CHASE
person 0.97
person 0.64