Perception for Autonomous Driving

Soohwan Kim

SWCS2020

Perception? Autonomous Driving?

Autonmous Systems

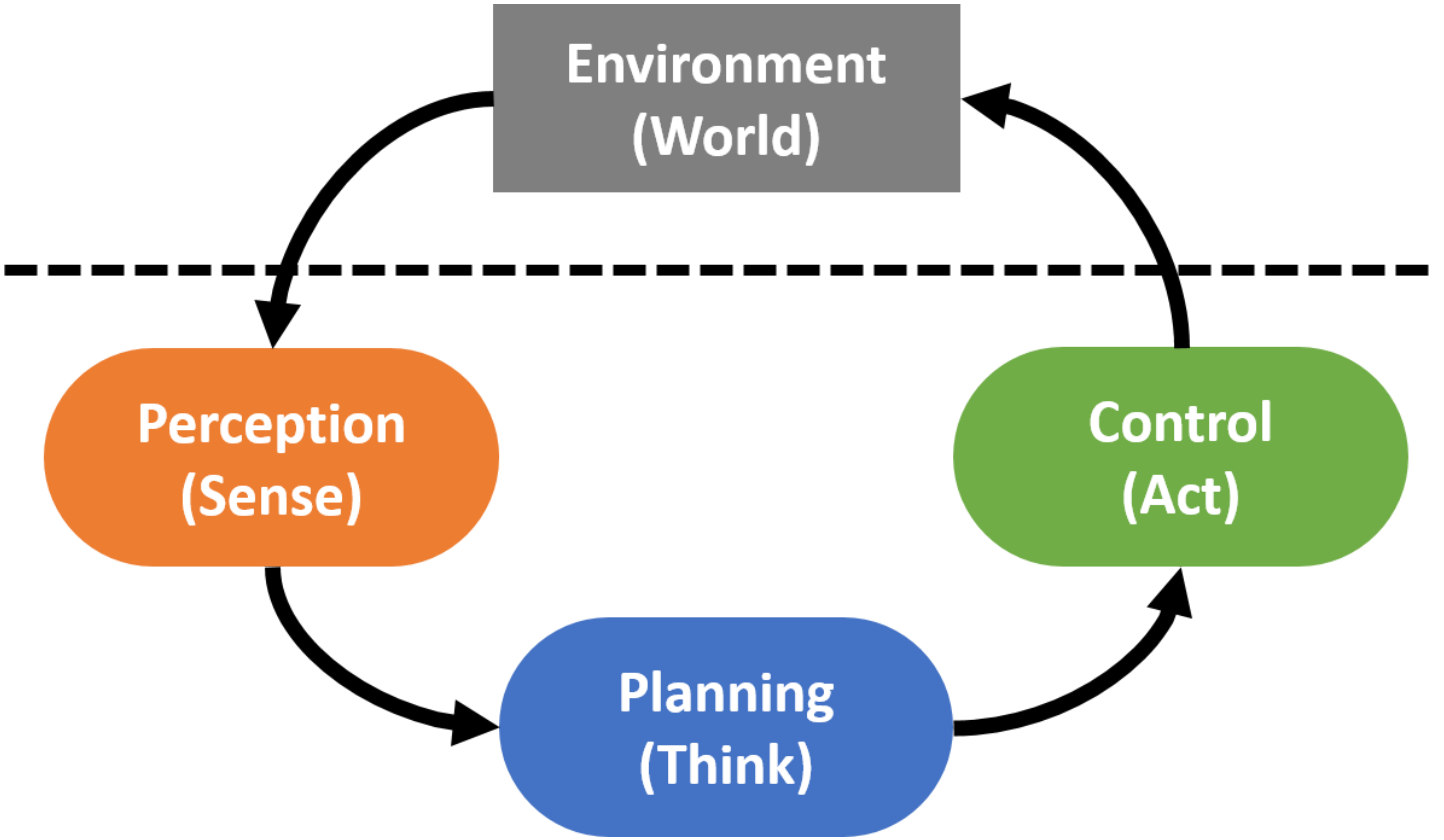
Boston Dynamics - Spot

DJI - Phantom 4

Waymo Self-Driving Car

Naverlabs - M1

Three Blocks of Autonomous Systems

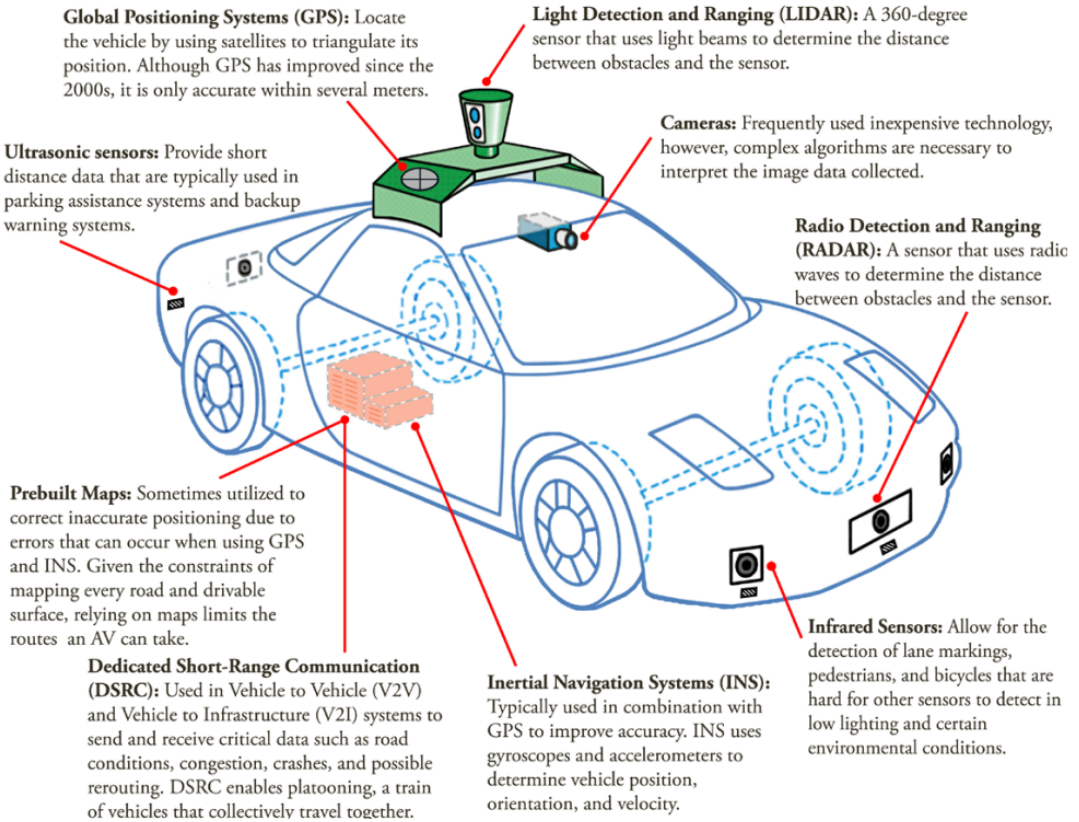


Three Blocks of Autonmous Systems

```
void main()
{
    // Initialization
    setup();

    // Infinite loop
    while(true)
    {
        // Step 1: perception
        sense();

        // Step 2: planning
        think();

        // Step 3: control
        act();
    }

    // Finalization
    shutdown();
}
```

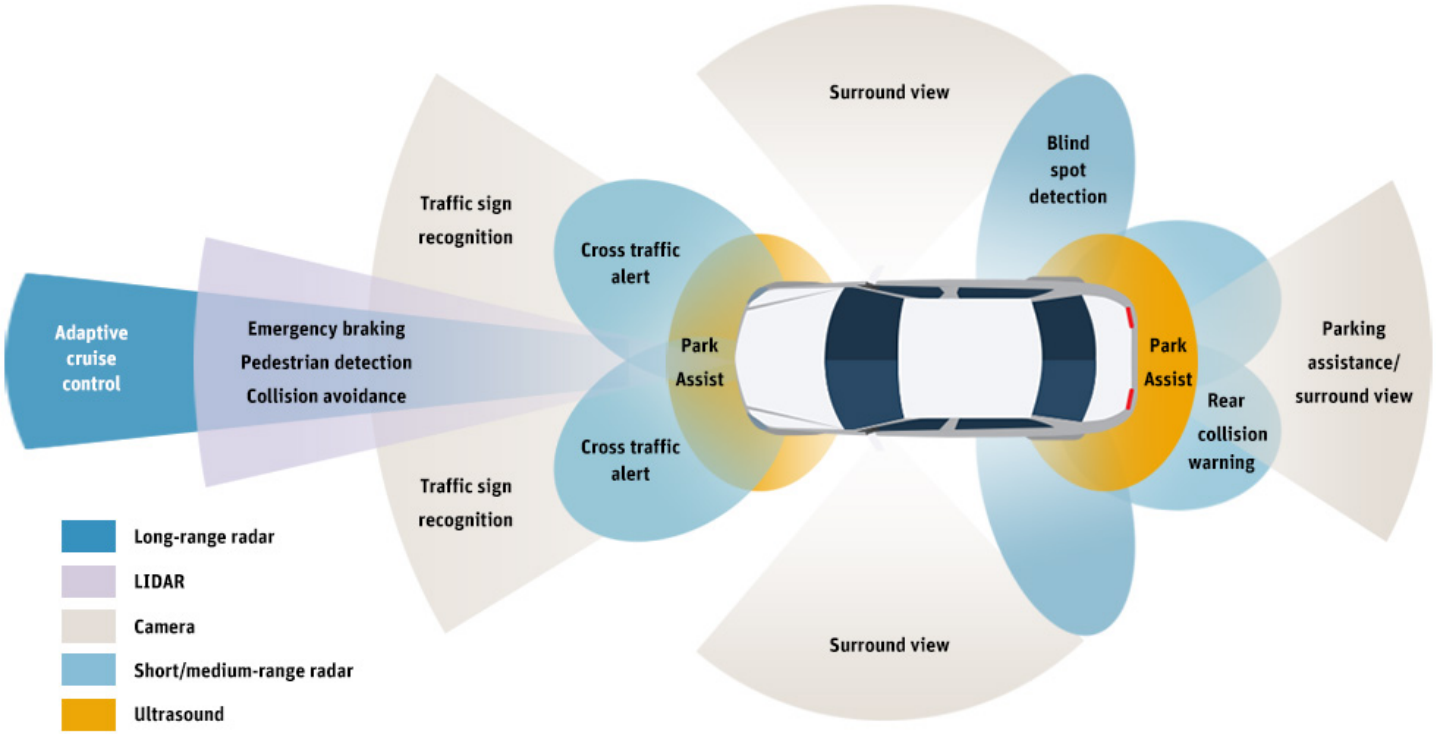
Sensors!

Sensors for Self-Driving Cars



Autonomous Vehicles, Factsheets - Center for Sustainable Systems, University of Michigan

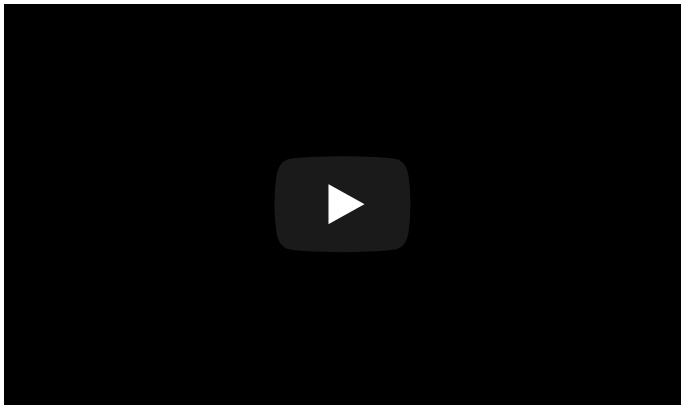
Sensors for Self-Driving Cars



https://www.ansys.com/about-ansys/advantage-magazine/volume-xii-issue-1-2018/autonomous-vehicle-radar

LIDAR (LIght Detection And Ranging)

Velodyne Lidar - Alpha Prime[1]



Velodyne Lidar - Alpha Prime[2]

Pros

- Generates point clouds
- Accurate point positions
- Works well even at night

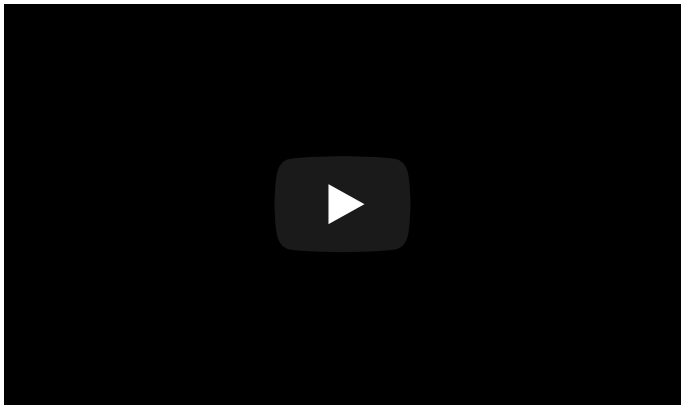
Cons

- Very expensive
- Sparse points
- Issues in fog, rain and snow

1. https://velodynelidar.com/products/alpha-prime/
2. https://www.youtube.com/watch?v=tZ8WbSNsNaU

RADAR (RAdio Detection And Ranging)

Aptive - ESR 2.5[1]



Texas Insrument - AWR1642[2]

Pros

- Long operating distance
- Effective for relative speeds
- Works in fog, rain, snow, night

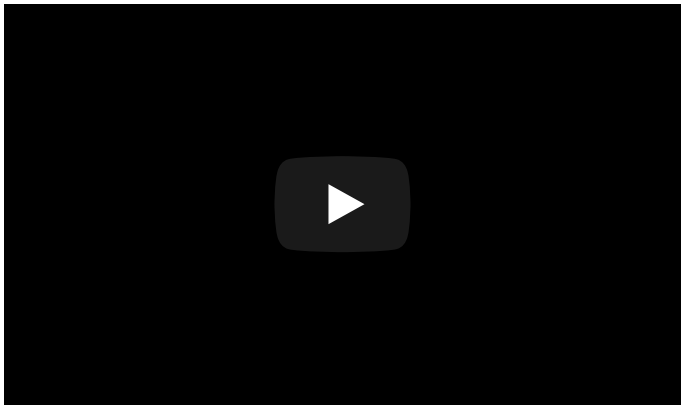
Cons

- Low resolution
- Very sparse
- Noisy and less accurate

1. https://autonomoustuff.com/product/aptiv-esr-2-5-24v/
2. https://www.youtube.com/watch?v=ziQjbVXcSts

Camera

Continental - SVC210[1]



KITTI Vision Dataset[2]

Pros

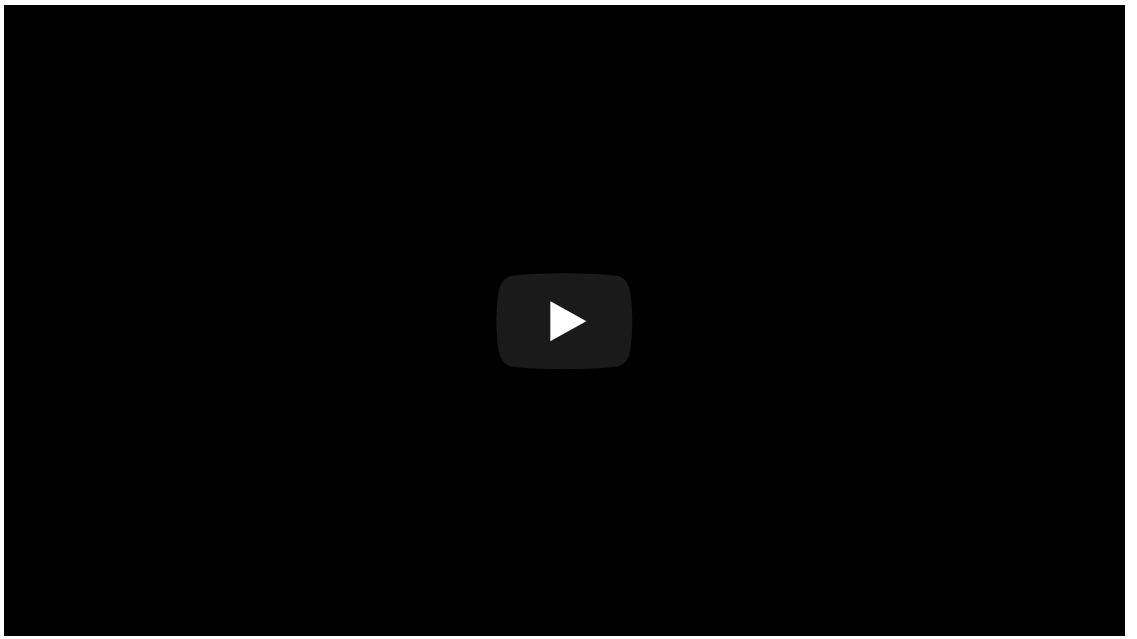
- Rich texture information
- Very affordable

Cons

- No depth information
- Issues in sun glare and shadow

1. https://www.continental-automotive.com/en-gl/2-Wheeler/Safe-Mobility/Sensors/Surround-View-Camera-SVC210
2. https://www.youtube.com/watch?v=KXpZ6B1YB_k

LIDAR vs. Camera

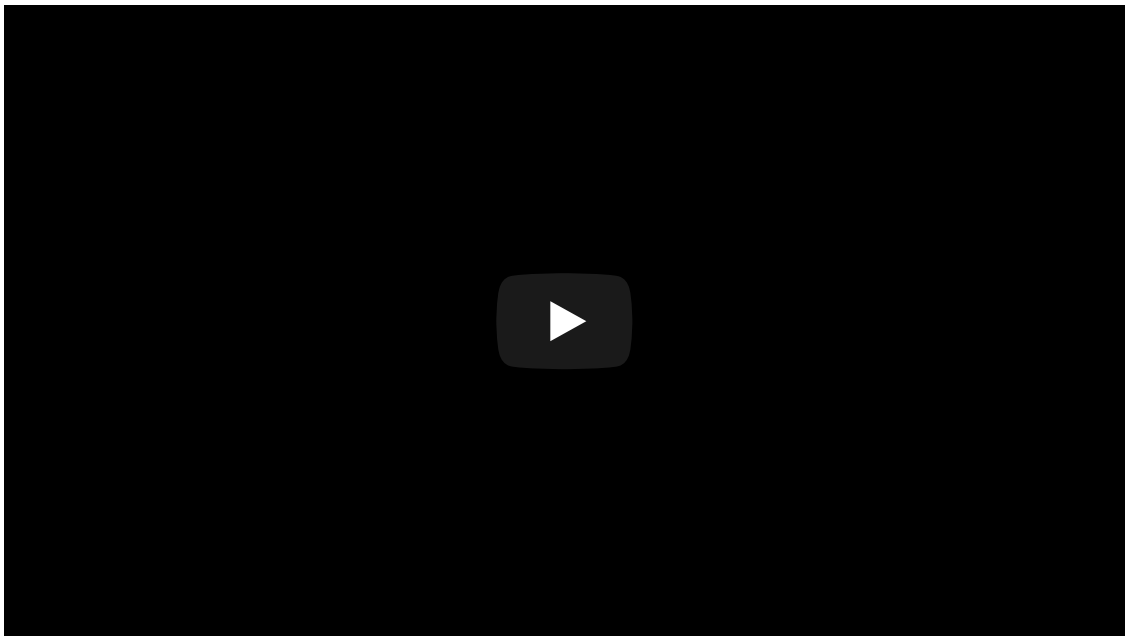


Velodyne Lidar - Lidar vs Camera Comparison[1]

Google vs. Tesla?

1. https://www.youtube.com/watch?v=y3Q7v5a0lnI

LIDAR vs. Camera

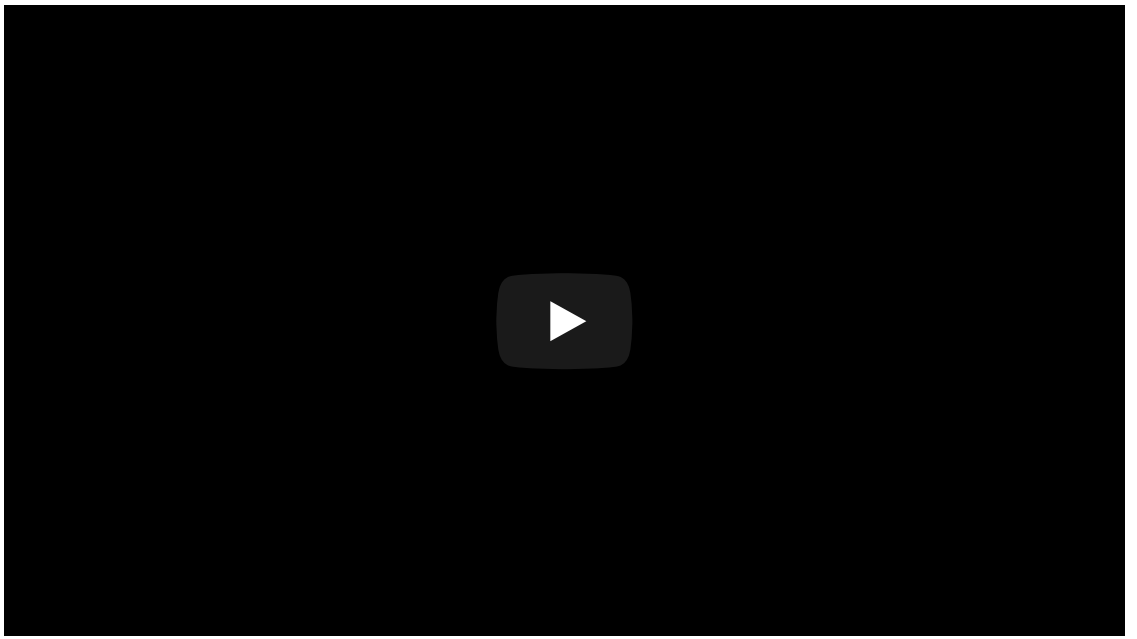


Waymo Self-Driving Car[1]

We Need Sensor Fusion!

1. https://www.youtube.com/watch?v=B8R148hFxPw

Camera-RADAR Sensor Fusion

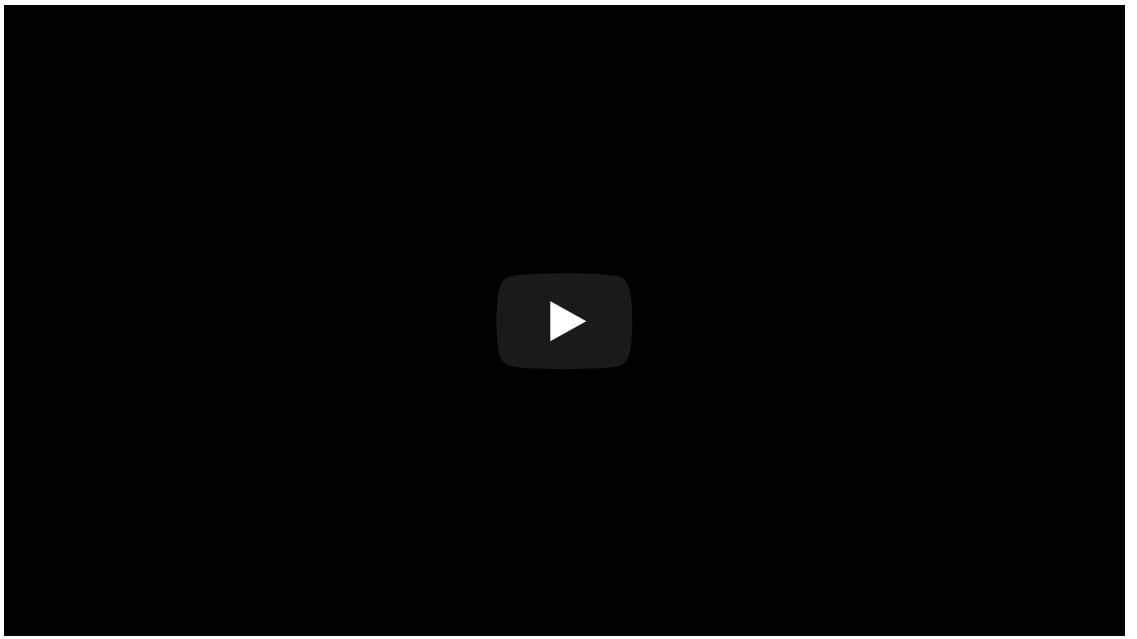


NVIDIA (6 Cameras and 8 RADARs) [1,2]

Detection + Position, Velocity and Acceleration

1. https://www.youtube.com/watch?v=cMlGyIJH5L8
2. https://developer.nvidia.com/blog/autonomous-vehicle-radar-perception-in-360-degrees/

LIDAR-Camera Sensor Fusion



LIDAR-CAMERA Fusion [1]

1. https://www.youtube.com/watch?v=XzLE-RW9wv8

GNSS and IMU

Global Navigation Satellite System

NovAtel - GPS-704-X[1]

[+] Global position, all weather

[-] Issues in downtown

Inertial Measurement Unit

Xsens - MTi-100[1]

[+] Egomotion, cheap, all weather

[-] Very noisy, bias

1. https://novatel.com/products/antennas/high-performance-gnss-gps-antennas/gps-704-x
2. https://www.xsens.com/products/mti-100-series

Other Sensors

- Odometry sensors
- Ultrasonic sensors
- Thermal cameras
- Solid-State LIDAR

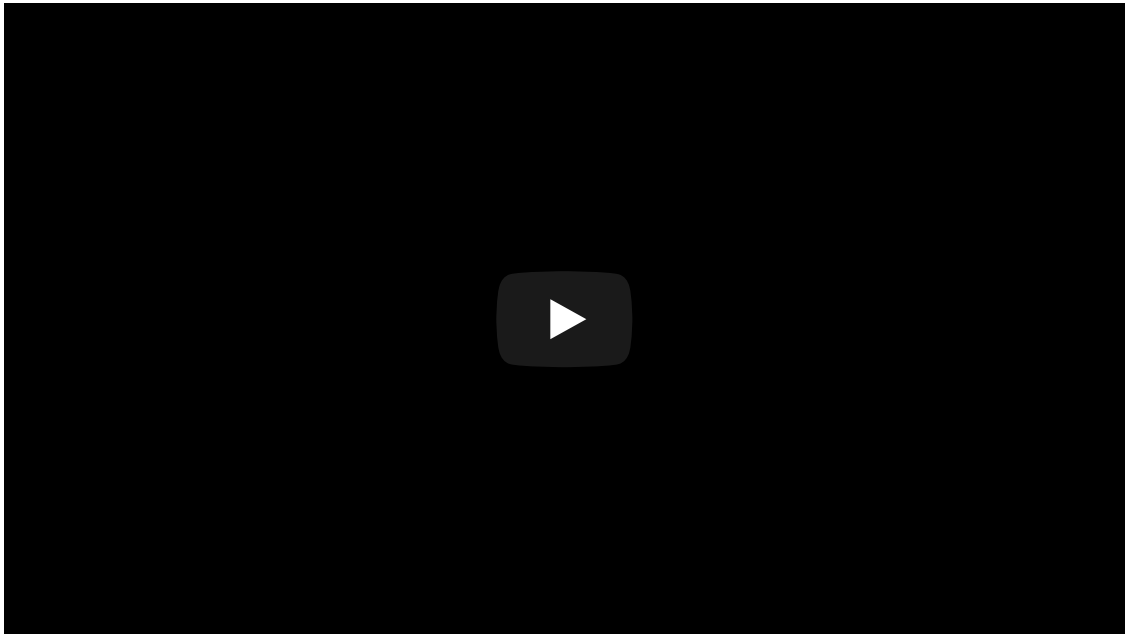
Perception for Autonomous Driving!

Perception for Autonomous Driving

1. Localization
2. Detection
3. Tracking
4. Estimation
5. Prediction

1. Localization

HD Maps

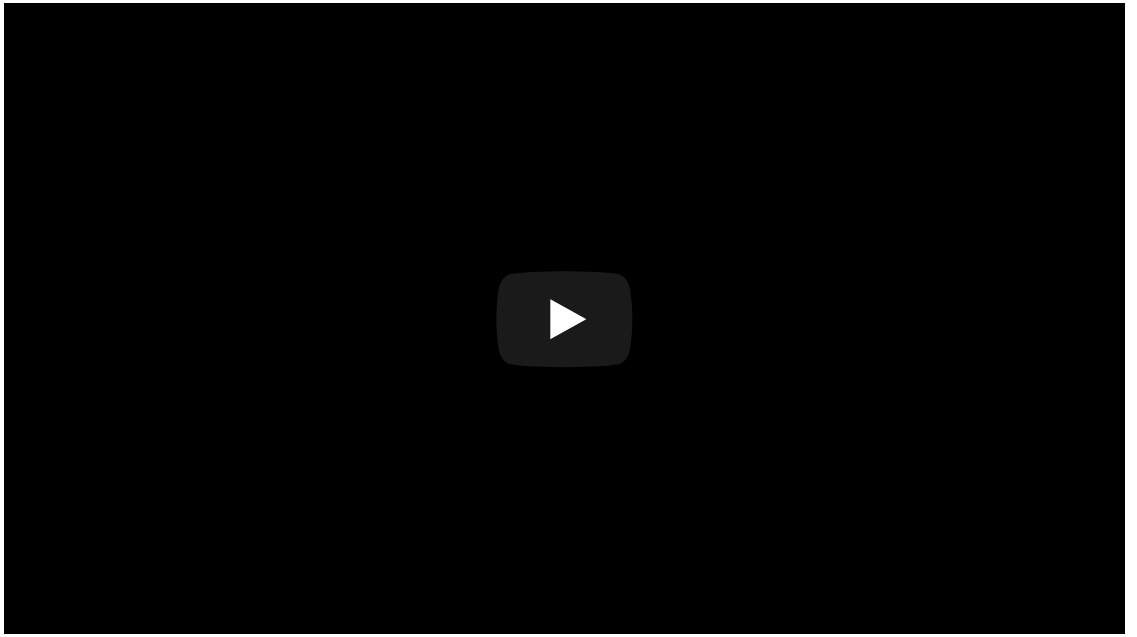


TomTom - HD Maps[1]

- SLAM using sesor fusion (LIDAR, camera, RADAR, GNSS, IMU, odometry)
- Lanes, center lines, road boundaries, intersections
- Traffic signs, traffic lights, poles, road markings

1. https://www.youtube.com/watch?v=ga5fW-QSXp0

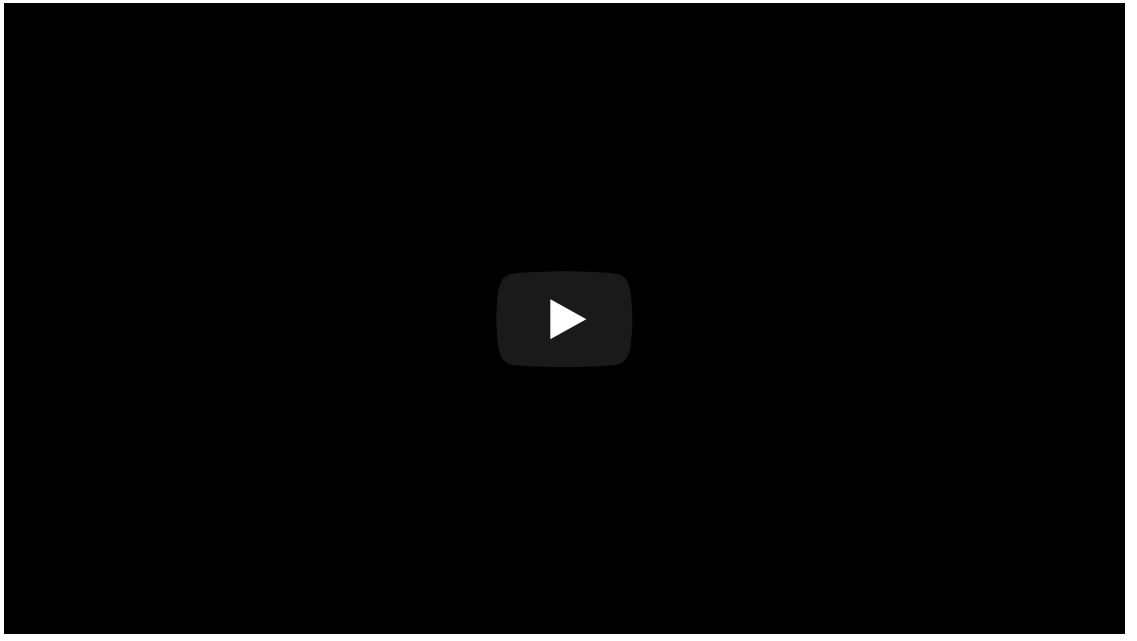
GNSS+INS vs. HD-map Based Localization



Naver Labs - HD Map Based Localization[1]

1. https://www.youtube.com/watch?v=PIf5fh2-3z4
2. https://www.youtube.com/watch?v=s0GK2EBpGZ8

Localization using Cameras

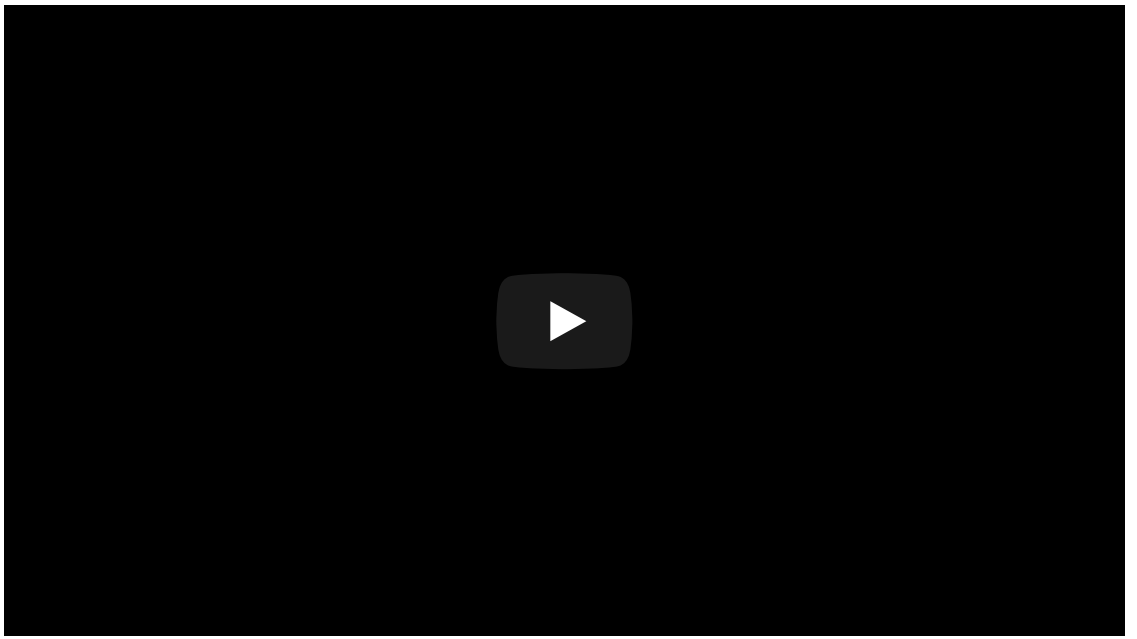


NVIDIA using cameras[1]

- Ego lane lines, center of ego lane, road boundaries
- Intersection lines, poles, traffic signs, traffic lights

1. https://www.youtube.com/watch?v=jcKnb65wpWA
2. https://www.youtube.com/watch?v=5IydCAYB5N0&t=20s

Localization using Sensor Fusion

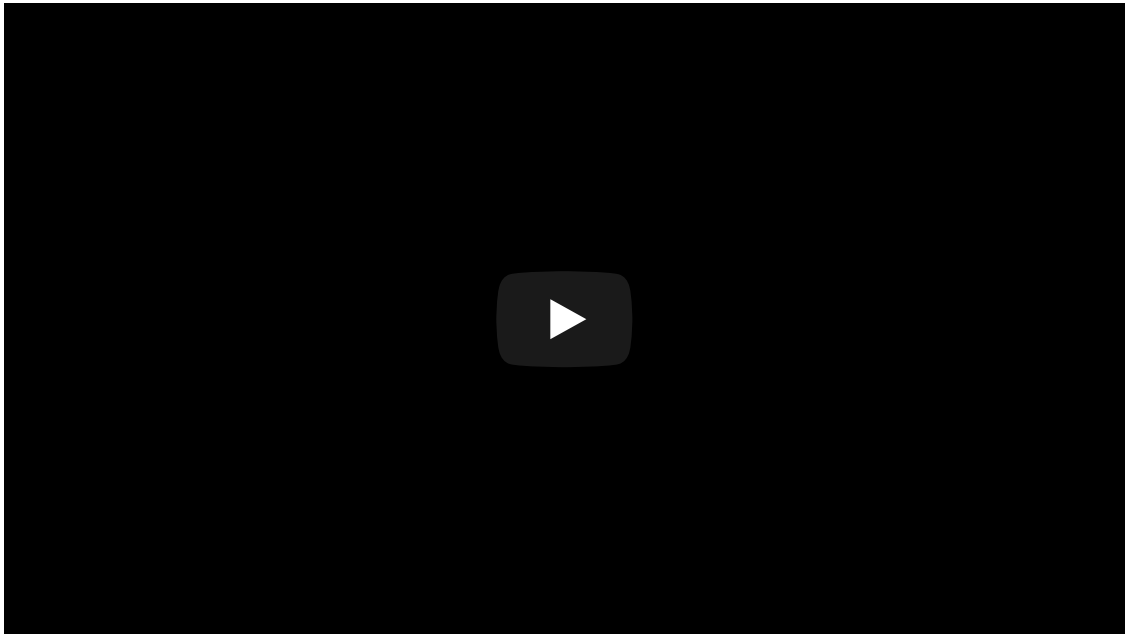


NVIDIA - Localization using camera, lidar, and radar layers[1]

1. https://www.youtube.com/watch?v=jcKnb65wpWA

2. Detection

Lane Detection

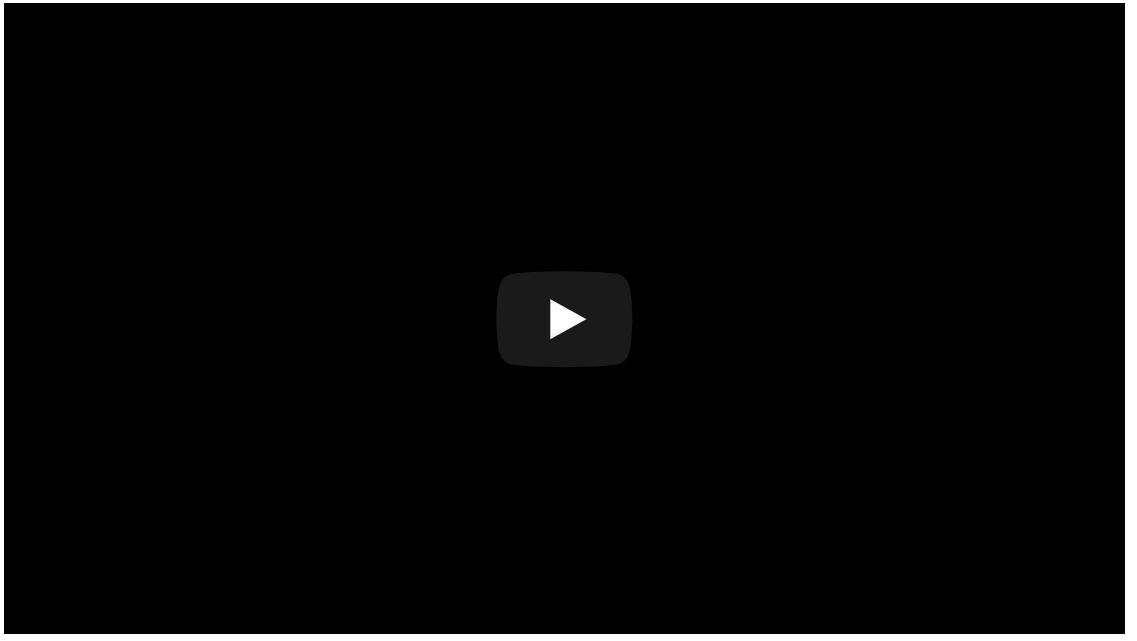


NVIDIA - LaneNet[1]

- Solid lane lines, dashed lane lines

1. https://www.youtube.com/watch?v=IzvlqCEYjg4

Object Detection

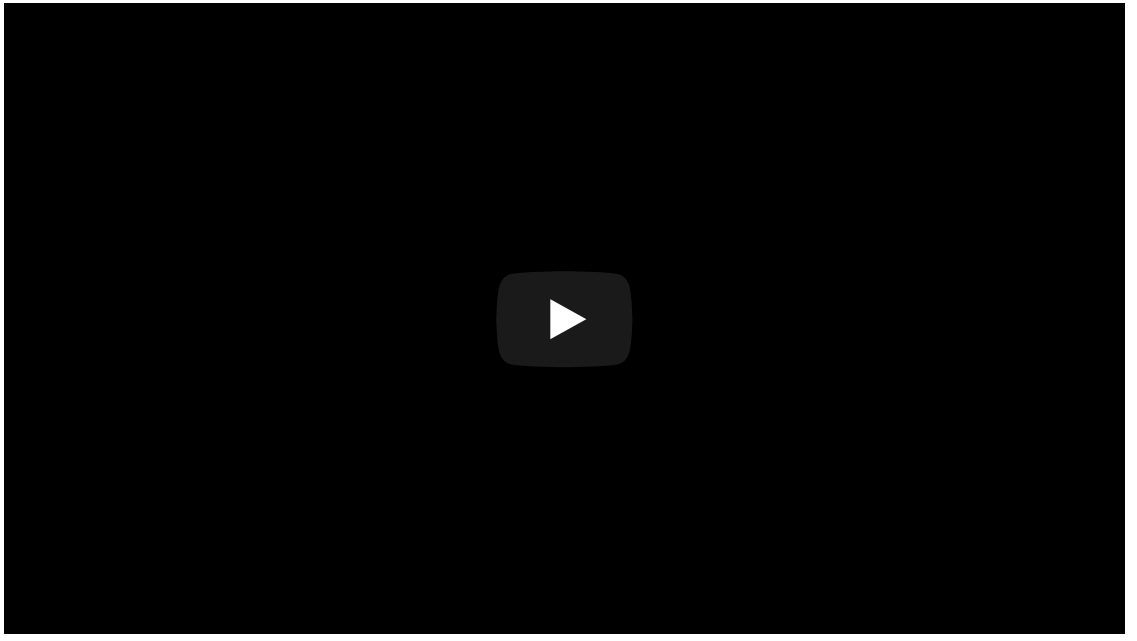


Waymo Self-driving Car at a Crowded School Crossing[1]

- Cars (back), cars (front)
- Pedestrians
- Traffic signs

1. https://www.youtube.com/watch?v=Vu8gmFhiGko

Object Detection

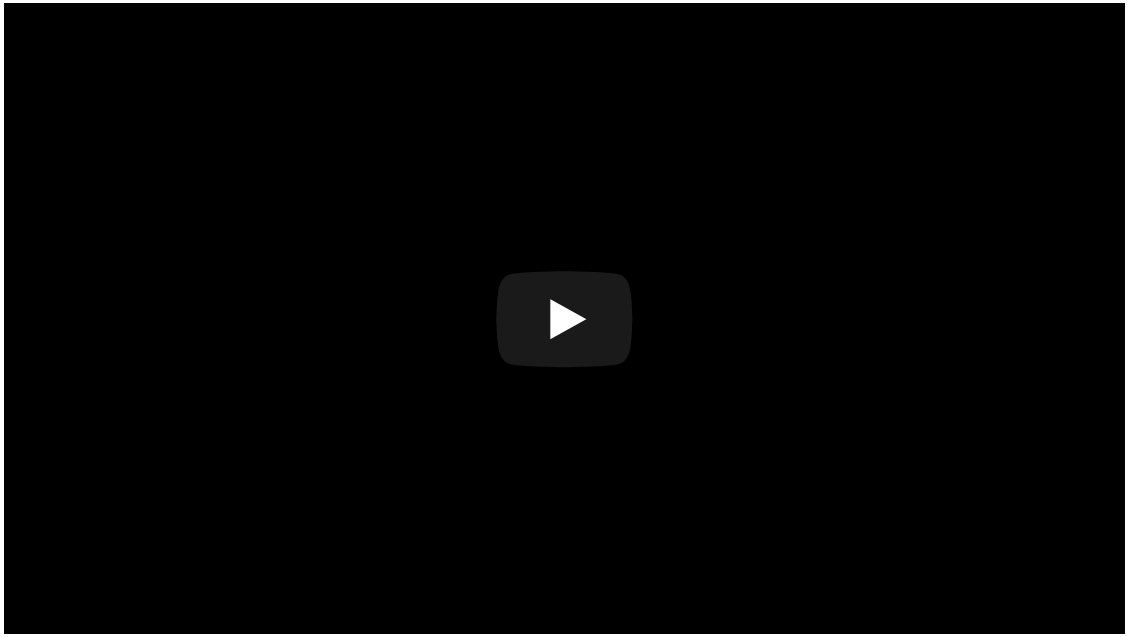


Waymo Self-driving Car Navigates a Police Controlled Intersection[1]

- Cars
- Pedestrians
- Traffic cones, intersections

1. https://www.youtube.com/watch?v=Vu8gmFhiGko

Map Feature Detection

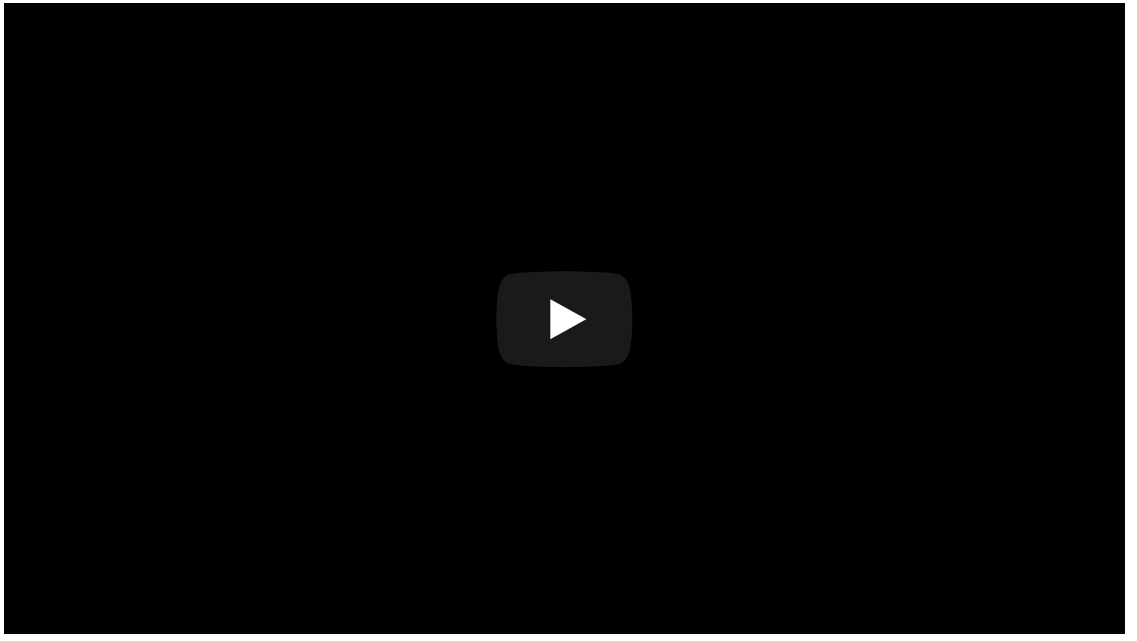


NVIDIA - MapNet[1]

- Lanes: Road boundaries, dashed lines, solid lines
- Intersections: Intersections, cross-traffic intersections
- Others: Poles, road markings

1. https://www.youtube.com/watch?v=dl8MI4vZmUY

Traffic Sign and Traffic Light Detection

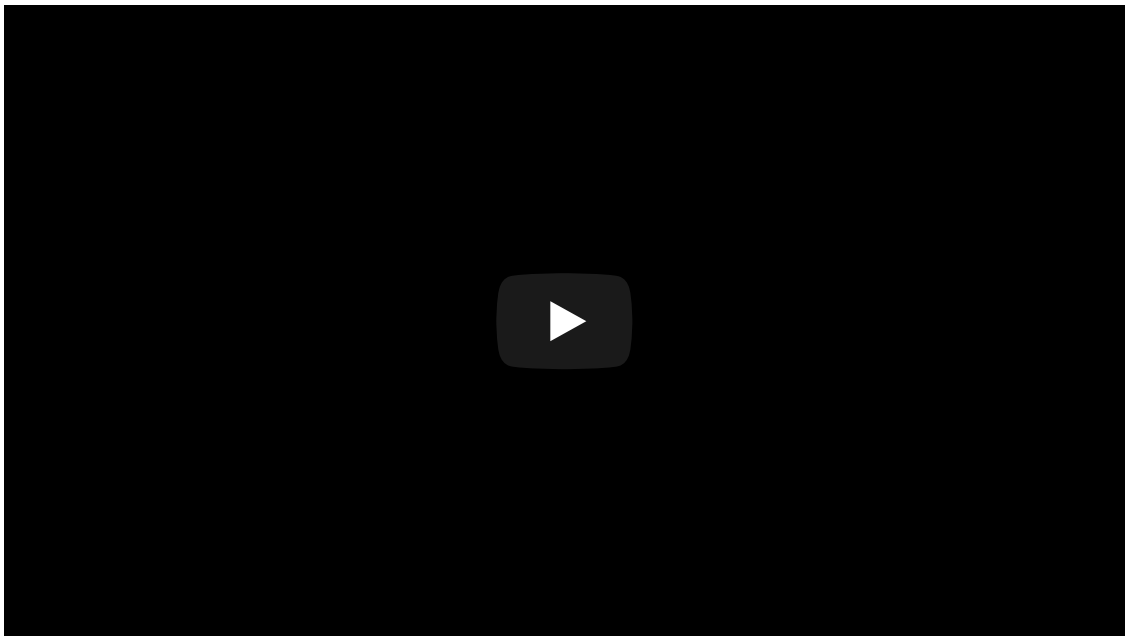


NVIDIA - WaitNet, LightNet, SignNet[1]

- WaitNet: intersections
- SignNet: traffic signs
- LightNet: red light, green light

1. https://www.youtube.com/watch?v=Uz5mIdRtdeA

Intersection Detection

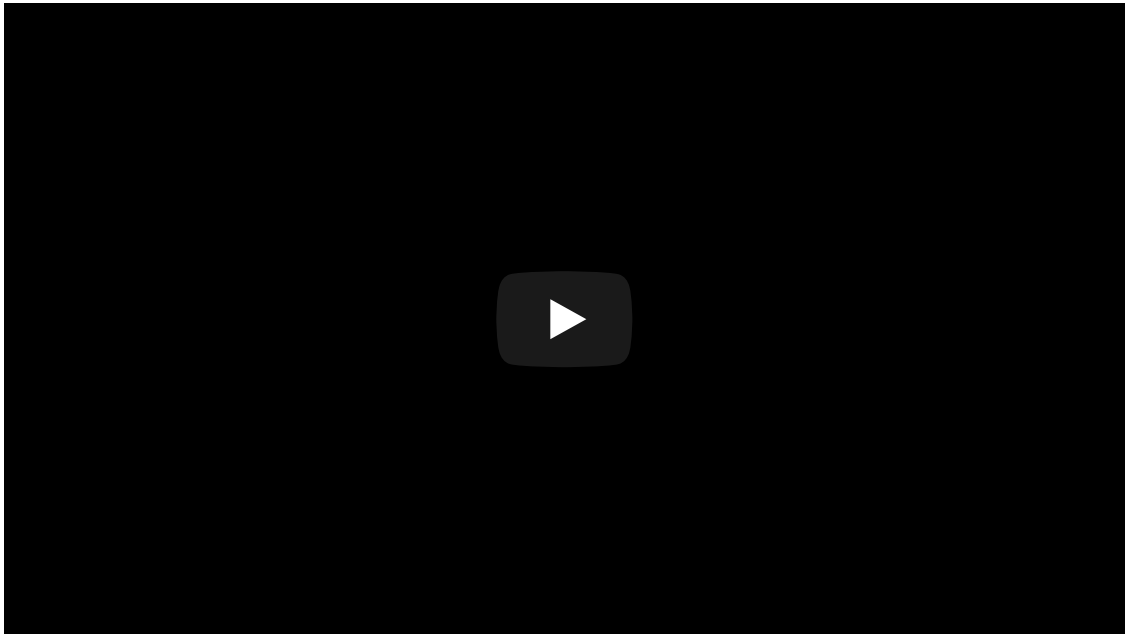


NVIDIA - Intersection Detection[1]

Where to stop and exit?

1. https://www.youtube.com/watch?v=KPLTA4S_3Yo

Parking Space Detection



NVIDIA - ParkNet[1]

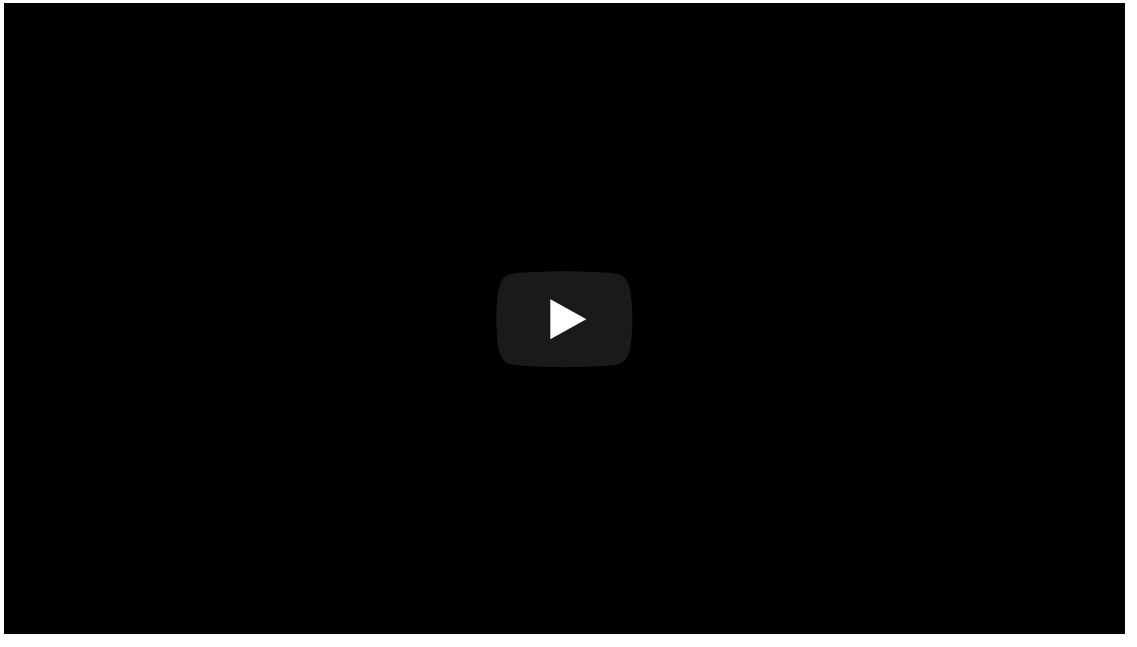
Where to park? How to enter?

- Parking lines, entry lines

1. https://www.youtube.com/watch?v=Bzfmc-PDwtM

3. Tracking

Feature Tracking

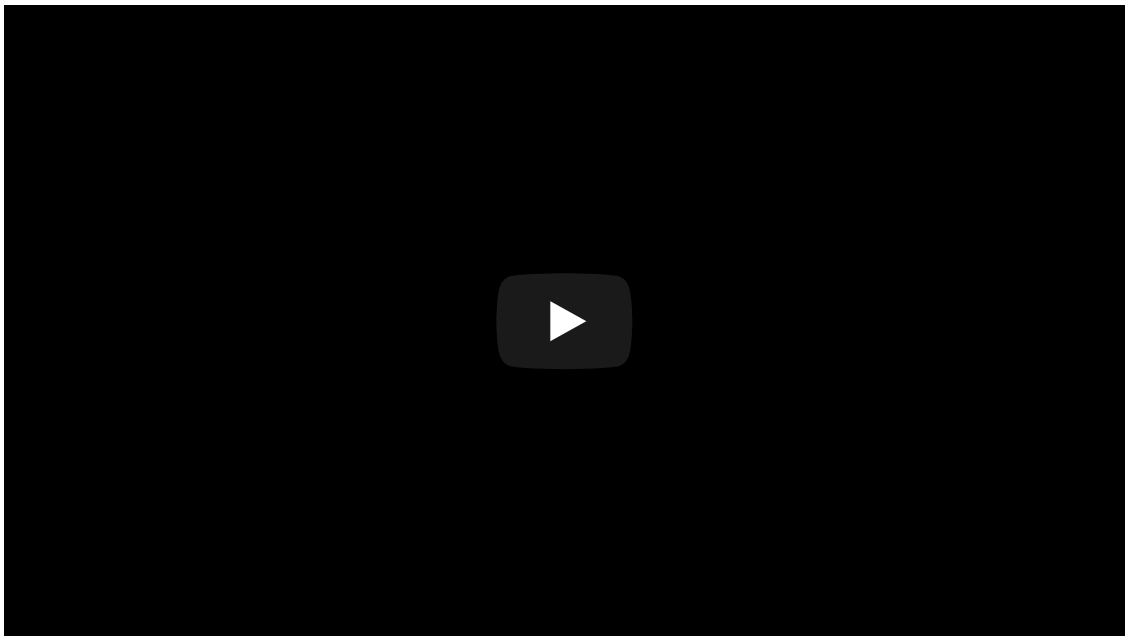


NVIDIA - Feature Tracking[1]

- Tracked features: features, feature track histories
- Detected Objects: moving away, getting closer, urgent

1. https://www.youtube.com/watch?v=y2X_7KwppoI

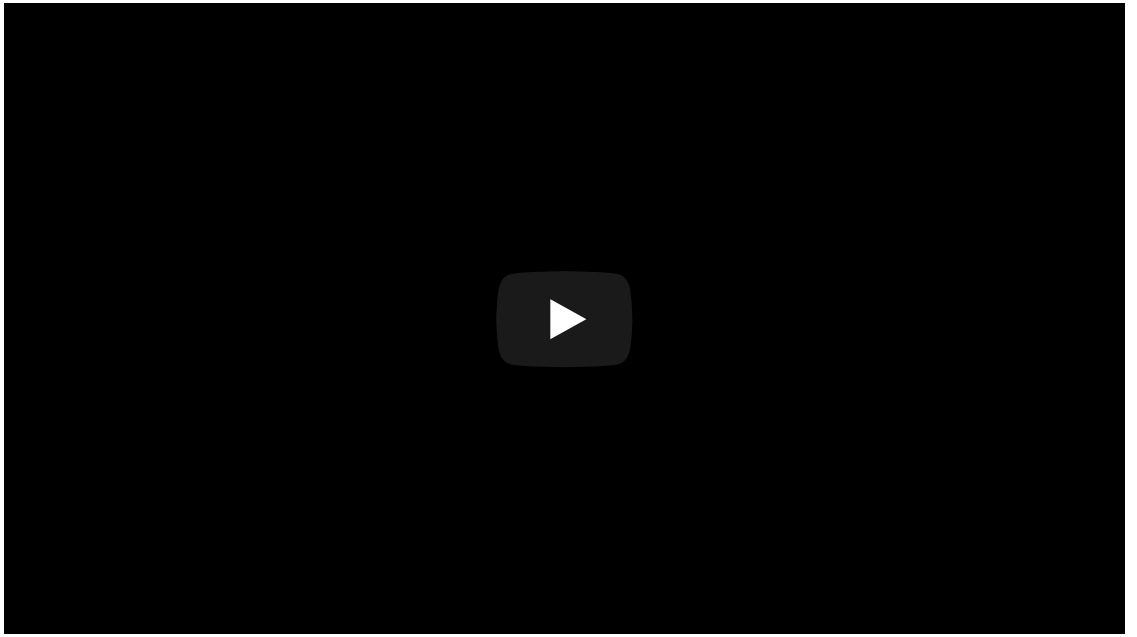
Object Tracking



NVIDIA -Surround Camera Object Tracking[1]

1. https://www.youtube.com/watch?v=aQwqD5cB2ck

Pixel-level Object Detection and Tracking



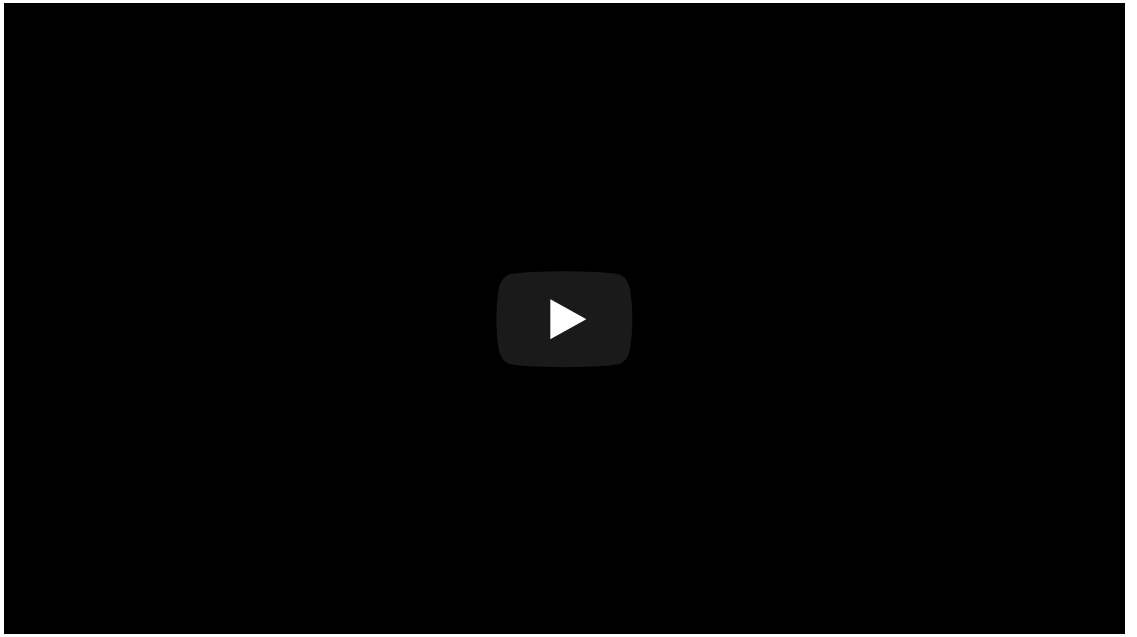
NVIDIA - Pixel-Perfect Perception[1]

- Detection (top): Cars, Pedestrians, Drivable space
- Tracking (bottom): object id (unique numbers and colors)

1. https://www.youtube.com/watch?v=HS1wV9NMLr8

4. Estimation

Depth Estimation from Single Camera



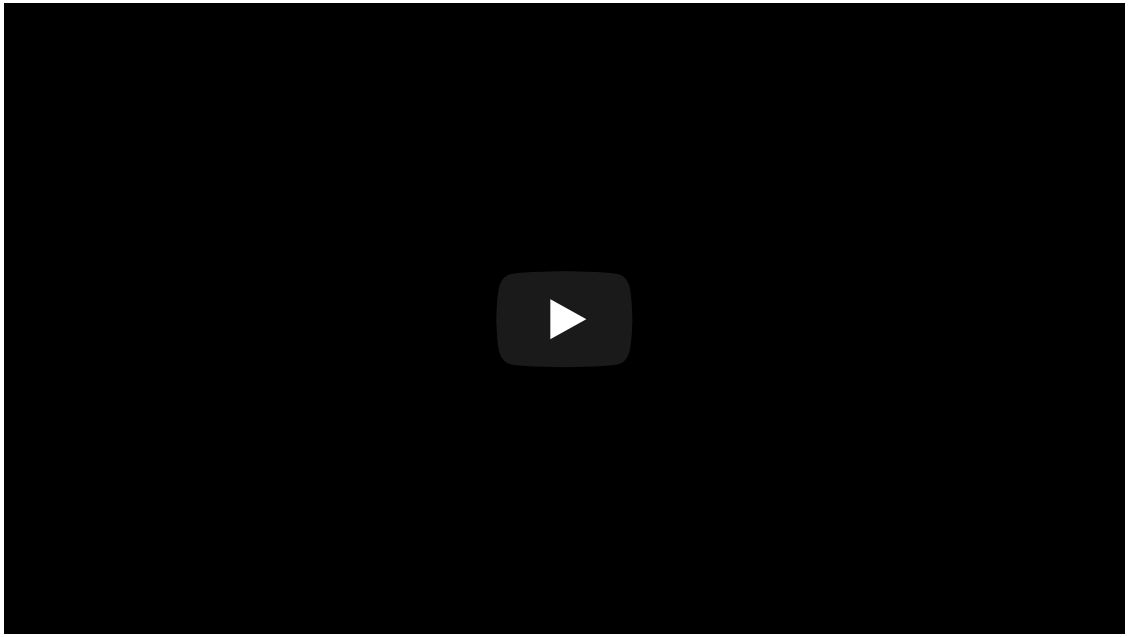
NVIDIA - Depth Estimation from Single Camera[1]

- Cars
- Pedestrians

1. https://www.youtube.com/watch?v=ftsUg5VlzIE

5. Prediction

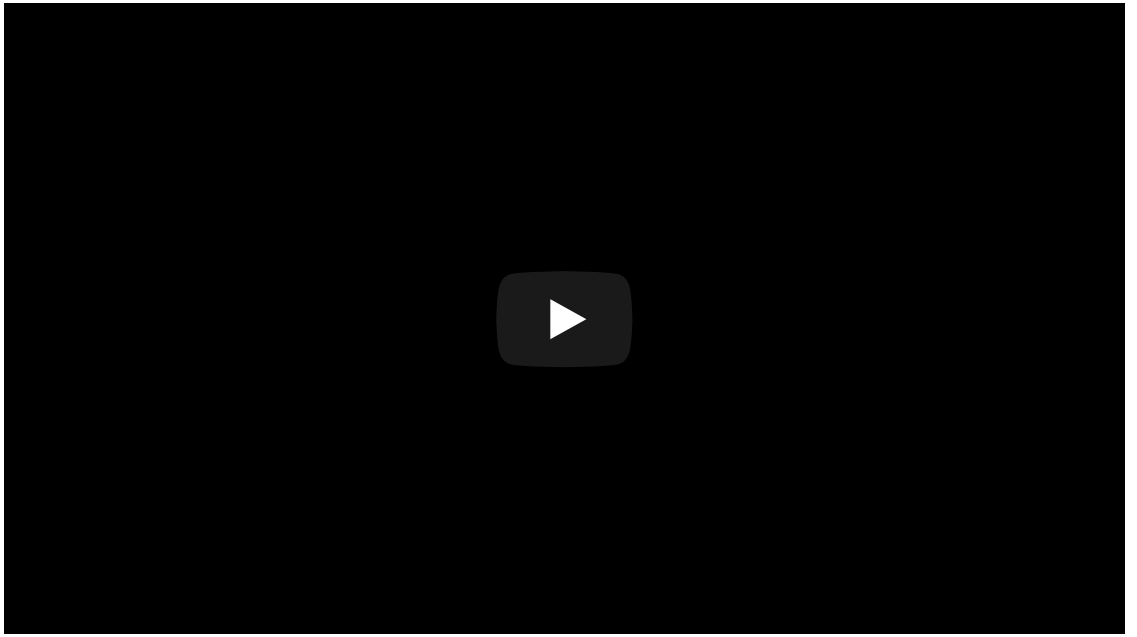
Car Trajectories



NVIDIA - Predicting moving objects using camera and radar[1]

1. https://www.youtube.com/watch?v=NG_O4RyQqGE

Pedestrian Trajectories



Waymo Self-driving Car Allowing Cyclists to Pass[1]

1. https://www.youtube.com/watch?v=NG_O4RyQqGE

Summary

Perception for Autonomous Driving

- Three Blocks
  1. Perception
  2. Planning
  3. Control
- Sensors
  1. LIDAR
  2. RADAR
  3. Camera
  4. GNSS, IMU
  5. Sensor Fusion
- Perception
  1. Localization: HD Maps
  2. Detection: objects
  3. Tracking: feature/object
  4. Estimation: depth
  5. Prediction: object trajectories

Thanks!

For slides with videos, visit https://soohwank.github.io/SWCS2020/