Robotics & Embedded Systems

Autonomes Fahren

SS 2019

Connected Vehicles, lane models and detection

Technische Universität München

V2X – Connected Cars

Vehicular communication Types:

- **Vehicular to Vehicular (V2V):**
  - Safety services, Cooperative driving, such as cooperative maneuver planning, crash warning, Direct link or indirect via mobile radio
- **Vehicular to Infrastructure (V2I):**
  - Traffic Management, Support for environment perception
- **Vehicular to Network (V2N):**
  - Services such as map-update, infotainment, Management of V2V link (network assisted mode)

V2X – Connected Cars

V2X requirements:

- Highly reliable communication links
- Low latency for selected applications (down to few milliseconds)
- High mobility support

V2X – Connected Cars

Vehicular service types:

- **Mobile broad band (MBB):**
  - high data rate, moderate delay constraints, e.g. video streams, map updates
- **Ultra-reliable low latency communication (URLLC):**
  - reception guarantee within contrained delay, mission-critical data like emergency brake notification
- **Machine type communication (MTC):**
  - regular reporting, small amount of data, not delay critical, e.g. status report of sensor data

V2X – Connected Cars

V2X use case impact:

- **Cooperative Lane Merging:**
  - Lane change maneuver actively coordinated among multiple vehicles using communication
  - Latency: 3ms, Reliability: 99.999%, Data Rate: 30Mbps
- **Truck platooning:** Windschatten fahren
  - Chain of vehicles driving with small in-between distances to save fuel and optimize traffic throughput. 5 to 7 % fuel reduction at 15 - 20 meters distance, 15 to 20 % fuel reduction at 5 – 8 meters distance
  - Latency: 10ms, Reliability: 99.99%, Data Rate: 65Mbp
- **Teleoperated driving:**
  - Vehicles (partially) controlled remotely
  - Latency: 5-20ms, Reliability: 99.999%, Data Rate: 1Mbps (DL) 25Mbps (UL)
- **See-Through:**
  - Visualize view ahead of frontal vehicle
  - Latency: 33 ms, Reliability: 99%, Data Rate: 10-16 Mbps

Requirements source Huawei

V2X – Connected Cars

Wifi 802.11p:

- IEEE 802.11p standard, derived from IEEE 802.11a
  - designed for short range comm.
  - burst transmission
  - Carrier sensing multiple access
  - Collision detection

- Simple design of protocol stack enables fast transmissions: end-to-end (E2E) delay of few ms

- Range up to 250 m (limited transmit power)

- Can connect to RSU if it is in communication range (also via hops using cars in vicinity)

  road side Unit

- Access to data center only if it is connected to RSU

- No quality of service guarantee – in congested networks, high probability of collisions

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4G Long term evolution (LTE):

- 4th generation of mobile radio
  - designed for mobile broadband
  - Scheduled transmissions based on requests for transmission
- Collision avoidance
- V2X enhancements: Additional V2V link (sidelink) with improvements for V2X Features
- Designed for non delay critical MBB data: end-to-end (E2E) delay of up to several tens of ms
- Range up to 500 m (sidelink, same power as 11p) and several km (V2N via base station)
- Quality of service guarantee thanks to link management at base station
- For available V2N connection, base station can also manage the sidelink (network assisted)

V2X – Connected Cars

low
Ultra Reliable Latency Communication

5G:

- **Issue:** LTE is not capable of fulfilling URLLC requirements, not even with enhancements
- **Goal:** Achieving 1ms communication with 99.99% reliability

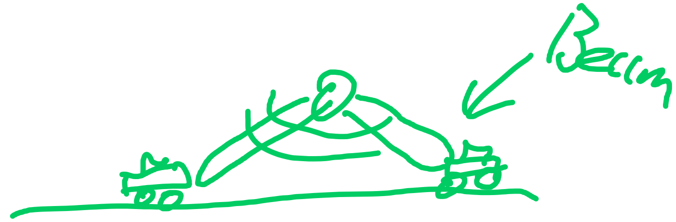
- **Issue:** Higher reliability and bandwidth requirements -> shorter coverage for cellular and v2v
- **Goal:** Improve with retransmission, antenna techniques, beam forming, beam tracking, network multi-connectivity

- **Availability:** The probability that a desired quality-of-service level can be met in the coverage area.

- **Achieve:** enhanced Mobile Broad Band (eMBB), massive Machine Type Communication (mMTC), Ultra Reliable Low Latency Communication (URLLC)

- Tradeoff between latency, reliability and throughput
- Tradeoff between bandwidth, availability and reliability

V2X – Connected Cars



Beam forming:

- **Use of multiple antennas at transmitter side:**
  - enables directing radio waves by spatial beam-forming
  - By concentrating transmit power into one direction, reception SNR can be increased
  - Using multiple beams allows to serve different users on the same frequency at the same time
  - Using multiple beams for one user opens up independent propagation paths offering diversity gains

- **Use of multiple antennas at receiver side:**
  - enables to suppress interference from other beam
  - Maximize Signal-to-Interence-and-Noise Ratio (SINR)
  - Increase link robustness

- **Mobile channel requires beam tracking and prediction:**
  - Beam has to follow the car to avoid signal loss.
  - As the trajectory of the car is known in advance, beam prediction becomes feasible.

Lane Models and Detection

Maximum monocular camera lane marker detection range:

$$\sim N \geq \frac{Cd}{w}$$

C: FoV opening angle Wide View

d: Maximum detection distance to lane marker

w: Lane marker width

N: Image resolution

Lane Models and Detection

Euler spiral, Clothoid:

Vehicle with constantly changing wheel angle drives a euler spiral or clothoid.

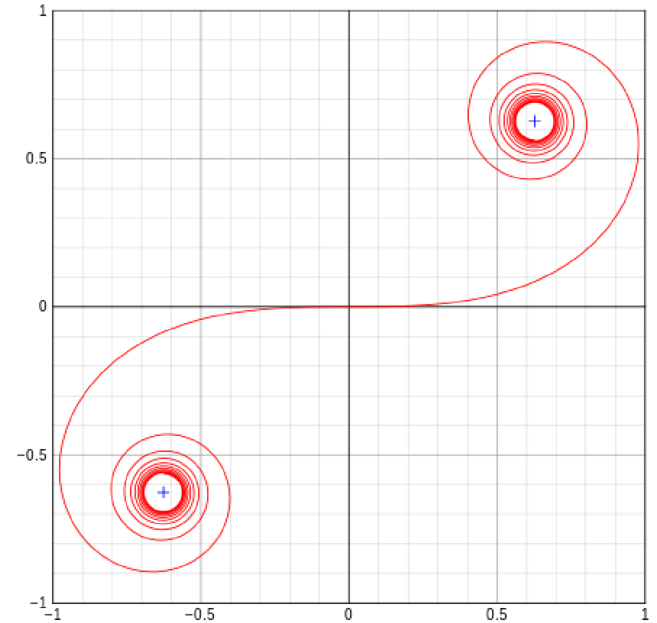
Road geometry is planned taking this into concern.

Constantly changing wheel angle => constantly changing curvature:

$$c(s) = c_0 + c_1 s$$

C_0 is the start curvature.

C_1 is the curvature change rate.



Klothoid, wiki commons

Lane Models and Detection

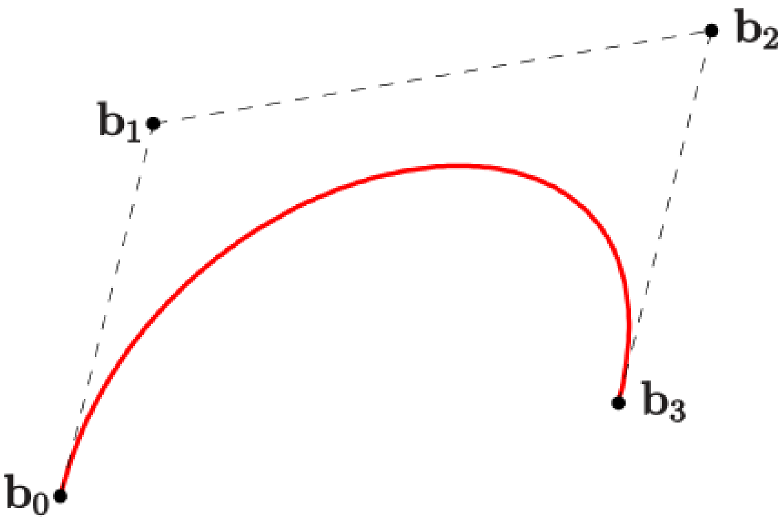
Bezier curves:

A Beziér curve of degree n is defined by n+1 control points $P0$, $P1$,…, Pn

A Bézier curve starts at $P0$ and ends at Pn

The Bézier line is inside the convex hull of the points

If one control point is changed, the whole line is affected



Bezier curve, wiki commons

Lane Models and Detection

Bezier curves:

Bézier curves are defined recursively w.r.t the degree n:

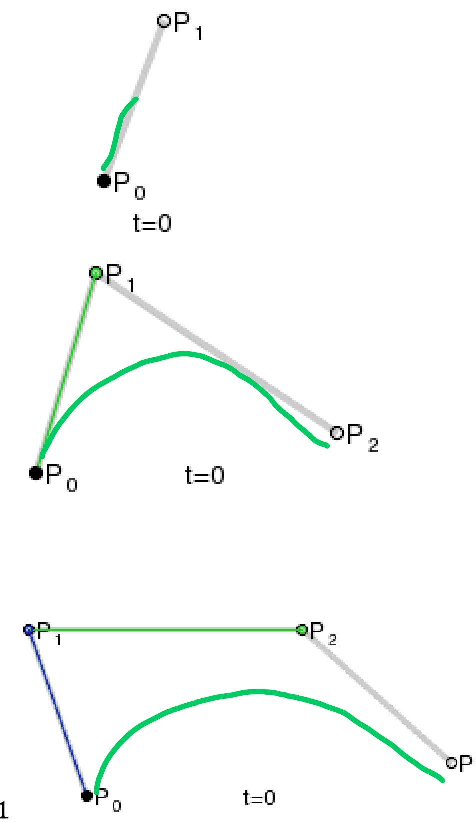
$B_{P0}(t) = P_0$ n = 0

$B_{P0P1}(t) = (1-t)B_{P0P1..Pn-1}(t) + tB_{P0P1..Pn}$ n > 0

For degree zero this means a Bézier curve through a single point is just the point

For degree one:

$$B_{P0P1}(t) = (1-t)B_{P0}(t) + tB_{P1}(t) = (1-t)P_0 + tP_1$$



This means that a Bézier curve through two points is just the straight line between these points

Bézier curves are called:

- Quadratic if they have degree 2
- Cubic if they have degree 3

Bezier curve, wiki commons

Lane Models and Detection

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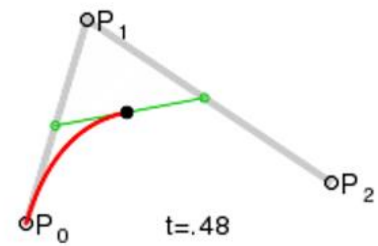
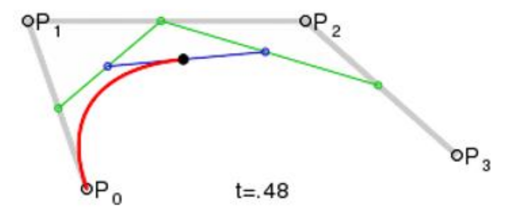




Bezier curve, wiki commons

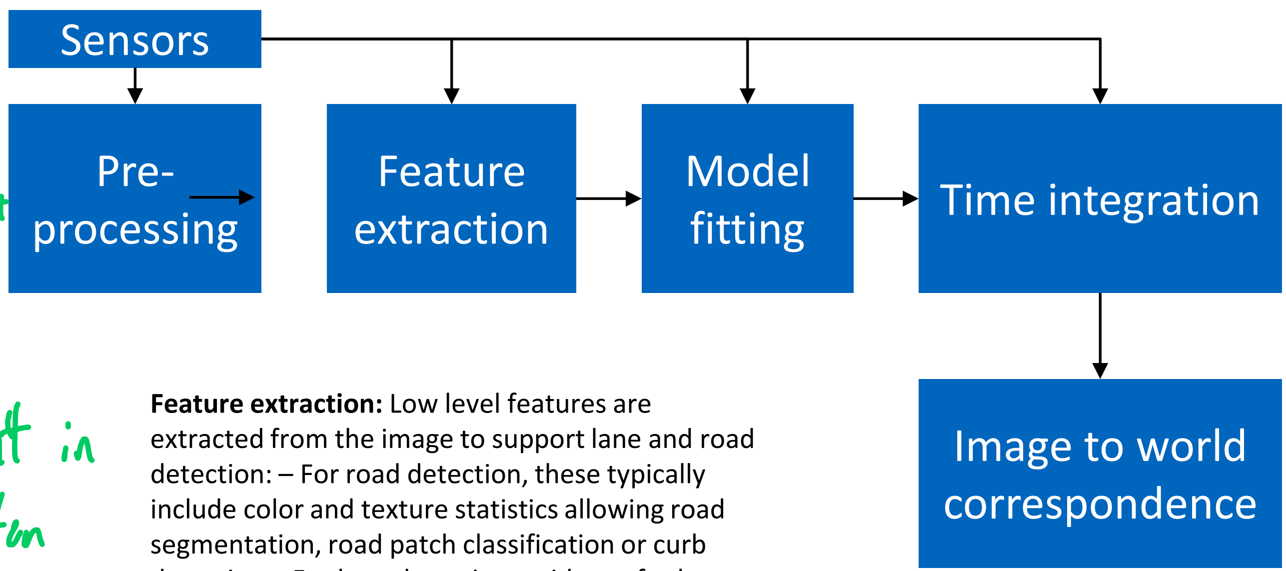
Lane Models and Detection

Pre-processing: Reducing clutter, enhancing features of interest, identification and removal of obstacle regions, weakening of shadows using preprocessing transformation applied to the entire image, accounting for over and under exposure cases by image normalization or by actively controlling the camera exposure, based on the image to world correspondence, truncation of the considered image area (e.g. region above horizon)

Time integration: Fuse road and lane hypothesis with previous frame and with global positioning information. Accepted if the difference between new and previous frame can be explained based on the vehicle dynamics.

Kalman Filter

2016 Q1 nicht



VL 11 nicht in den alten Klausuren

Feature extraction: Low level features are extracted from the image to support lane and road detection: – For road detection, these typically include color and texture statistics allowing road segmentation, road patch classification or curb detection – For lane detection, evidence for lane marks is collected

Model fitting: A road and lane hypothesis is formed by fitting one of the geometric road/lane models discussed in the previous chapter to the evidence gathered. Fitting can be done in the original image or in the bird's eye view

Image to World: provides services of translation between image and ground coordinates, using assumptions about the ground structure and camera parameters