GNSS in the Future
Automotive World

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Outline

• What does vehicular navigation encompass?
• Location, routing and obstacle avoidance
• Accuracy requirements and what GNSS delivers
• V2V [Vehicle To Vehicle] in the context of V2X and ADAS
• The role of GNSS & challenges in urban areas
• A V2V test
• On-board sensors to aid GNSS
• On-board collision avoidance sensors
• V2X communication technologies
What is Vehicular Navigation?

- Vehicle location on a map with respect to roadways and infrastructure [V2I] such as curbs, buildings, services, etc
- Directions from one location to another
- Location, management, routing of service vehicle fleets [e.g. police, taxis, public services]
- Obstacle avoidance [other vehicles, pedestrians, infrastructure] - V2V, V2P, V2I
- V2N (Vehicle-to-Network): Traffic, road and weather conditions in real-time, hence communication requirements
Vehicle location and navigation Accuracy

1. General location for route finding: 10-20m
2. Which road [With respect to parallel roads]: 5m enough

Can GNSS achieve this on reasonably open roads?
- Yes using chipsets in single point (SP) mode (and compass for heading).
- Can be done with smartphones
SAE V2V accuracy performance requirements

- Time: 1ms UTC
- Position: 1.5m, 1σ, open sky
- Elevation: 3m, 1σ, open sky
- Speed: 1km/h, 1σ
- Heading: 2-3°, function of speed, 1σ, open sky
- Steering wheel angle accuracy (5°, 3σ)
- Acceleration accuracy (.3 m/s² longitudinal and lateral, 1 m/s² vertical; 1σ) – open sky

SAE: Society of Automotive Engineers
CAMP VSC 6 Consortium, ITS America, On Board System Requirements for V2V Safety Communications for Light Vehicles, 6Jun16
V2X (V2V, V2P, V2I, V2N)

- Qualcomm vision but also fairly generic

Ref: Cellular-vehicle-to-everything-C-V2X-technologies, Qualcomm, June 2016
V2X and ADAS (Advanced Driver Assistance Systems)

GNSS is only one component of V2X

V2X provides higher level of predictability and autonomy
Complementing other sensor technologies

- Radar
  - Bad weather conditions
  - Long range
  - Low light situations

- Camera
  - Interprets objects/signs
  - Practical cost and FOV

- Lidar
  - Depth perception
  - Medium range

- Ultrasonic
  - Low cost
  - Short range

Brain of the car to help automate the driving process by using:

- Immense compute resources
- Sensor fusion
- Machine learning
- Path planning

V2X wireless sensor
- See through, 360° non-line of sight sensing, extended range sensing

3D HD maps
- HD live map update
- Sub-meter level accuracy of landmarks

Precise positioning
- GNSS positioning
- Dead reckoning
- VIO
What happens to GNSS in a city?

- Many NLOS signals still reach the antenna through reflection [Multipath]
- Signals are also attenuated and noisier
- Reflected ranges are longer than LOS ones
- Satellite geometry somewhat preserved
- GNSS location still possible but with degraded accuracy
- Signal interference vulnerability

LOS & NLOS: Line Of Sight and Non-LOS
Signal interference Vulnerability

- **Jamming**: Intentional and unintentional radio frequency propagation in GNSS bands disrupts operation and service.

- **Spoofing**: Deliberate interference that aims to mislead receivers into generating false PVT solutions.

- **Multipath**: Signal reception from multiple sources causing signal fluctuation and loss of signal lock.

In car jammer by G. Lachapelle, University of Calgary
Prepared by Dr. A. Broumandan, PLAN Group
How well can a smartphone do?

- Downtown test, 30-50 km/h, 9Mar17, 4xloop, up to 60 story buildings
- Samsung S7 (blue) dashboard, iPhone 6 (red) back seat passenger pocket
- Similar performance, given different phone locations
- No difference between cellular on and off
- Similar results with a handheld unit with no map
- Why is it so good in such an environment? Data filtering
Better filtering for vehicle (higher speed), pedestrian on sidewalk and close to buildings [same smartphone used in both cases – May 2016]
Urban canyons – Attenuation

• In open sky conditions, C/No should be of the order of 40 to 45 dB-Hz, hence attenuation below reaches 30 dB-Hz; signal quality is marginal at the lower end of the range (at the 10 to 15 dB-Hz level)
2009 GNSS V2V Tests

- Test conducted in 2009 by Univ of Calgary for CAMP (Crash Avoidance Metrics Partnership)

<table>
<thead>
<tr>
<th>Position type</th>
<th>Accuracy (m)</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference of position (DPOS)</td>
<td>1–3</td>
<td>• Low bandwidth</td>
<td>• Position accuracy</td>
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<tr>
<td></td>
<td></td>
<td>• Only vehicle position data is shared</td>
<td>• Decreased accuracy when uncommon satellites are used.</td>
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<tr>
<td>Differential GPS (DGPS)</td>
<td>1–2</td>
<td>• Better position accuracy than DPOS</td>
<td>• High bandwidth</td>
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<tr>
<td>Carrier phase positioning (RTK)</td>
<td>0.01–1</td>
<td>• Best position accuracy</td>
<td>• Position data and addition GPS data messages need to be shared</td>
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<tr>
<td></td>
<td></td>
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<td>• High bandwidth</td>
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V2V Testing Equipment & Procedure

- Test conducted in 2009 for CAMP, 2 vehicles, 40 hours of data
2009 GNSS V2V test results

- Test conducted in 2009 for CAMP, 2 vehicles, 40 hours of data
- FA: Full Availability for given receiver pair; FAWA (nm): FA with error ≤ n metres
- AT-Along track, XT-across track
- AW: geodetic GPS L1 receiver (rx) with WAAS
- BW: automotive grad GPS L1 rx with WAAS. B: BW without WAAS
- BW24: same as BW with assuming 24-SV GPS constellation

<table>
<thead>
<tr>
<th>Receivers</th>
<th>Processing method</th>
<th>FA (%)</th>
<th>FAWE (1.5 m)</th>
<th>FAWE (5 m)</th>
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<tr>
<td></td>
<td></td>
<td>AT (%)</td>
<td>XT (%)</td>
<td>AT (%)</td>
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<td>Host</td>
<td>Remote</td>
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<td>RTK</td>
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<td>DPOS</td>
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Bridging GNSS Outages

• Vehicle-borne sensors:
  • **Odometers**, including differential odometry techniques to measure direction change
  • **Inertial sensors**: accelerometers & rate gyros
  • **Full gyro & accelerometor triads** (IMUs)
  • **Partial IMU & other sensor combinations**
  • **Magnetometers** (direction finding)
  • **Visual passive** (cameras)
  • **Map matching** (e-maps stored on vehicles)
• Combinations of these sensors with degraded GNSS measurements is complex due to noise, biases and drifts

G. Lachapelle, University of Calgary
• IMU advantages/limitations
  • Self-contained, *resistance to interference*
  • Translation and rotation information
  • High short-term relative accuracy but high long-term drifts

• Above opposite to GNSS and due to complementarity, integration is natural…

• IMU-GNSS integration approaches:
  • Loosely coupled (e.g. position + position)
  • Tightly coupled (measurements + measurements)
  • Ultra-tightly (Deeply) coupled

• IMU performance-versus-cost metric is improving rapidly – See regular commercial product announcements for ever more performing systems
Vehicle collision avoidance methods and sensors

- **Passive visual (cameras):** Detection and classification of vehicles, pedestrians, cyclists, lane marking (lane departure warning), traffic signs [e.g. Mobileye N.V.].

- **LiDAR (Light Detection And Ranging):** Highly accurate, RT 3D mapping, hence detection, day & night, all weather. Used in some autonomous vehicles [e.g. Quanergy solid state LiDAR demo, 150m range, $250]

- **Radar:** Use of RF for range, angle and velocity, all weather. Radar-on-a-chip are low cost, good range, day & night, all weather at 77GHz, no colour or optical character resolution

- **Ultrasonic:** Sound waves, excellent at short range, all conditions, small & low cost

- **Sum of the above + GNSS & in-car sensor aiding:** SLAM (Simultaneous Location And Mapping). Works underground in the absence of GNSS signals

On-board avoidance sensor comparison

Range in figures is in metres

V2V & V2I communication – U.S. DOT DSRC Approach

• U.S. DOT Intelligent Transportation Systems: DSRC (Dedicated Short Range Communications)

• Legacy IEEE 802.11p standard

• U.S. FCC allocated 75 MHz of spectrum in the 5.9 GHz band [5850-5925 MHz] for use by ITS vehicle safety and mobility applications:
  • Active safety transportation applications
  • Reliable, secure communications
  • Fast communication speed low latency
  • Invulnerability to extreme weather
  • Tolerance of multi-path transmissions
  • Technology based on standards to enable interoperability

Qualcomm Alternative V2X Communication Proposal

• V2X – Cellular Vehicle-to-Everything
• Expansion of V2V and V2I for enhanced mobile broadband, mission-critical services, internet of things, 3D map live map updates, etc. [1]
• Allows for communication evolution to full 5G and more capacity for future mobile applications
• …would allow certain unlicensed wireless devices to operate in the same spectrum as V2V systems - Opposed by DOT and automakers due to issues such as interference) [2]
• Debates on-going, e.g. [3]

[1] the-path-to-5g-cellular-vehicle-to-everything-c-v2x, Qualcomm, 22Feb2017
V2X potential applications

- Blind spot warnings
- Forward collision warnings
- Sudden braking ahead warnings
- Do not pass warnings
- Intersection collision avoidance and movement assistance
- Approaching emergency vehicle warning
- Vehicle safety inspection
- Transit or emergency vehicle signal priority
- Electronic parking and toll payments
- Commercial vehicle clearance and safety inspections
- In-vehicle signing
- Rollover warning
- Traffic and travel condition data to improve traveler information and maintenance services
- the CONNECTED & AUTONOMOUS CAR is here and evolving…


Also, watch the (forthcoming) May 2017 issue of GPS World – Available online
...and so are multiple GNSS constellations
Conclusions

• On-board vehicle sensor capabilities and [decreasing] costs are evolving **VERY** rapidly – Already in autonomous cars

• Non-GNSS collision warning sensors will be dominant for urban applications, hence everywhere for V2X

• GNSS will continue to be the method for general location and routing on maps, and V2N - Mobile phones can provide these services in an effective manner [e.g. Google Maps]

• Fuller integration of GNSS with on-board sensors will occur, in the context of SLAM, to contribute to V2X [accuracy & reliability]