PNT in smart cities – are we ready for autonomous driving?

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• Smart and connected communities/Smart city
• Autonomous driving in a smart city
• Levels of autonomy
• Testing the performance of autonomous vehicles
• Are we there yet?
• Summary and conclusions
Smart Cities are those that have a base level of connectivity and integrated municipal services.

Cities built on *Smart* and *Intelligent* solutions and technology that will lead to the adoption of at least 5 of the 8 following smart parameters:

- smart energy
- smart building
- smart mobility
- smart healthcare
- smart infrastructure
- smart technology
- smart governance and
- smart education, smart citizen


Credit: www.frost.com
26 smart cities are expected by 2025, 50% of which will be in Europe and North America
At present: smart communities projects in many cities worldwide
No smart city yet...Amsterdam, Barcelona, NYC, London, Nice, Singapore
Six trends that will define smart cities in 2018

2017 TRENDS

- Ride-sharing services’ growing influence
- Dockless bike-sharing
- Deliberate development
- P3s and municipal collaborations (P3s = public private partnerships)
- Local-level dependence
- Affordable housing plans
- Building smart cities from scratch

2018 TRENDS

- Equitable innovation
- Electric vehicle (EV) infrastructure expansion
- 5G technology
- Cybersecurity
- Blockchain
- Microtransit

Dockless Lime Bike in San Francisco. Credit: Lime Bike
What is smart mobility?

- Advanced traffic management system (ATMS)
- Parking management
- ITS-enable transportation pricing system
- Connected vehicles/cooperative navigation
- Autonomous vehicles
- Electric vehicles
- Shared rides
- Integrated multimodal transportation system

Goals
- low emissions and low carbon footprint
- low or no congestion = more efficient and less stressful mobility
- no accidents and fatalities
Self-driving cars: motivation

- According to the Global Road Crash Data, traffic crashes are the major cause of death and injuries worldwide:
  - ~1.3 million fatalities/year, on average 3,287 fatalities/day

- In the US alone, there are over 37,000 fatalities and 2.35 million injuries in road crashes each year:
  - of these, 94% are caused by human error

- The cost of traffic crashes is incredibly high:
  - $518 billion globally and $230.6 billion in the United States
  - Unless action is taken, traffic crashes are predicted to be the fifth leading cause of death by 2030

- Traffic congestion and parking are increasingly problematic

- Aging population
Driverless technology is rapidly evolving
High-definition geospatial data + PNT: enablers of high-accuracy localization and better safety
Crowdsourcing: becoming a dominant data acquisition technology (Big Data, Big Geo Data)
Communication: crucial aspect!
Full autonomy… is still a long way
But wait, there is more…. 

- V2V/connected vehicles
- V2I/V2X
- Layered sensing/communication

- Collaborative navigation
  - UAS
  - Airplanes
  - Ground vehicles
  - Pedestrians
  - Etc.
Are we ready for autonomy?

- Autonomy level (AL) ↔ Guidance, Navigation and Control (GNC)
- Technology readiness level (TRL) ↔ System integration, testing, performance evaluation, integrity monitoring (SITPI)
- GNC ↔ SITPI
- ATRL = Autonomy and Technical Readiness Level
- Environmental complexity
- Task complexity
- Ethical, legal and societal implications
- Policy, etc.…
- **GOAL**: implement a safe, efficient and robust system for individual, civil and commercial applications

source: [http://www.mdpi.com/2504-446X/1/1/5](http://www.mdpi.com/2504-446X/1/1/5), Akash Vidyadharan et al., 2017
<table>
<thead>
<tr>
<th>Level</th>
<th>Autonomy level</th>
<th>Technology readiness level</th>
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<tbody>
<tr>
<td>1</td>
<td>Remote control</td>
<td>Basic principles</td>
</tr>
<tr>
<td>2</td>
<td>Automatic motion control</td>
<td>Application formation</td>
</tr>
<tr>
<td>3</td>
<td>System fault adaptive</td>
<td>Technology concepts &amp; research</td>
</tr>
<tr>
<td>4</td>
<td>GPS assisted navigation</td>
<td>Tech development &amp; proof of concept</td>
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<tr>
<td>5</td>
<td>Path planning &amp; execution</td>
<td>Low fidelity/laboratory component testing</td>
</tr>
<tr>
<td>6</td>
<td>Real time path planning</td>
<td>System integration &amp; testing</td>
</tr>
<tr>
<td>7</td>
<td>Dynamic mission planning</td>
<td>Prototype demonstration &amp; operation</td>
</tr>
<tr>
<td>8</td>
<td>Real time collaborative mission planning</td>
<td>Prototype operation in realistic mission scenario</td>
</tr>
<tr>
<td>9</td>
<td>Swarm group decision making</td>
<td>Mission deployment</td>
</tr>
<tr>
<td>10</td>
<td>Full autonomous</td>
<td>Fully operational status</td>
</tr>
</tbody>
</table>

source: [http://www.mdpi.com/2504-446X/1/1/5](http://www.mdpi.com/2504-446X/1/1/5), Akash Vidyadharan et al., 2017

Are we ready for autonomy?
Since 2015, Navigant has scored the 20-or-so companies working on self-driving technology on 10 different criteria related to strategy, manufacturing, and execution:

- How good is their technology?
- Can they manufacture it at scale?
- What’s their plan for getting it to the masses?

After that, Navigant ranks the companies in four categories:

- Leaders
- Contenders
- Challengers, and
- Followers

GNSS/PNT has become an essential element of major contemporary technology developments notably including the IoT, Big Data, Augmented Reality, Smart Cities and Multimodal Logistics.

In turn, the advent of 5G, Automated Driving, Smart Cities and the IoT will accelerate further proliferation and diversification of GNSS-enabled added-value services. Their annual revenues will hit $225 bln in 2025, more than 2.5 times higher than the expected GNSS device and service revenues, mostly within, across and beyond conventional GNSS market segments.
Aside from providing navigation solution to self-driving cars, GNSS/PNT offers numerous opportunities to:

- **plan** new infrastructure and improve the existing one based on measuring traffic flows – e.g. longitudinal traffic flow data informing future infrastructure investment decisions
- **decrease** CO$_2$ emissions coming from the transportation sector – e.g. smart bus stops and efficient traffic light phasing
- **ensure** safety based on citizens’ reports of hazardous locations – e.g. combining citizens’ emergency reports with CCTV data
- **improve** infrastructure monitoring, optimize maintenance intervals and reduce the costs for upkeep – e.g. combining data on the use of bridges and sensor-provided status of various elements.
The Ohio State University

Geospatial technology/PNT and autonomy

Smart City

Smart Retail

Smart Mobility

Smart Home

Smart Health

Smart Energy
Geospatial technology/PNT and autonomy

- Smart City
- Mobility
- Smart Retail
- Smart Health
- Smart Home
- Smart Energy
- Smart Mobility
Smart City Mobility

Driverless vehicles Navigation

Local
- Collision avoidance
- Defensive driving
- Energy minimization

Global
- Path planning
- Route optimization
- Energy minimization

Imaging sensors
- No need for maps
- High definition maps are helpful

GPS
- Maps needed

No GPS
- High definition maps needed!

Intelligent geospatial database
- Part of the Smart City IT system
- V2X communication
Vehicle localization

Localization accuracy required by autonomous driving:

- High accuracy: 3-10 cm
- Single frequency GPS is not enough (2-5 m)
- More complex GPS/GNSS processing requires special infrastructure (RTK, PPP)
- ”Urban canyon effect” still a problem
- Commercial grade IMUs suffer from large drift errors and navigation-grade IMUs are still expensive

Solution:

- Map matching algorithms: reliable and accurate
- Map matching requires precise a priori map
Growing developments in autonomous vehicle technology call for accurate, reliable and robust ground reference.

Post-processed GNSS/IMU data are generally used to generate reference 6DOF trajectory:

- Assessment of localization and mapping results

3D object detection and tracking, as well as semantic segmentation of the driving environment must also be tested.

- Fully georeferenced omnidirectional vision and LiDAR, Radar etc. data are used to generate reference benchmark environment.
Autonomous driving: requirements

- Full situational awareness of the vehicles in the system: sensing, navigation, communication (V2V, V2I/V2X)
  - Requires added infrastructure, however, the autonomous system must still be able to function correctly when not available
  - High cost

- Reliability, accuracy, coverage and security of the navigation systems
  - Standards and performance requirements of GNSS software, hardware, and differential services must meet the requirements of autonomous vehicle
  - Increase accuracy of lower cost platforms by utilizing multi-frequency, multi-constellation sensor fusion and precise point positioning
Reliability, accuracy, coverage and security of the navigation systems (cont.)

- Ability to rely on GNSS in auto-guidance applications requires incorporation of integrity functionalities into GNSS products.
- GNSS alone will not meet all of these stringent requirements due to signal attenuation, interference.
- IMUs, LiDARs, Radars, cameras, and ambient signals of opportunity, such as Wi-Fi, cellular and digital TV must augment GNSS.
  - Cost? Complexity? Reliability?
- Collaborative real-time tracking mechanisms must assure reliable navigation when a driving network malfunctions.
Equally crucial is the requirement to develop new safety standards for new motor vehicles and motor vehicle equipment, and

To modify existing standards as necessary changing circumstances such as the intro technologies and modes of mobility
GPSVAn is a general sensor platform with highly accurate georeferencing system. Data acquisition capabilities to support:

- Creating accurate high-definition maps
- Providing sensor data streams to support driverless vehicle technology research
Sensors: various data streams
KITTI data, widely used benchmark, SPIN Lab CDD/IMU/SLAM solution
OSU Campus benchmark dataset for autonomous vehicle testing

- Acquire data streams from mobile platforms, including vehicles, bicycles, pedestrians, etc.
  - Essential to testing vehicle sensing and maneuvering capabilities
- Create a high-definition map of the test area using mobile data collection and additional surveying of the area for benchmarking
- Test the potential of Big Data/Data Analytics technology for map production based on highly redundant multi-sensor data, including crowdsourcing.

Total Data Acquired: 6 hr (5 TB)
Object space reconstruction: all LiDAR data
Dynamic object detection on the road
Video object detection for multiple object tracking
End to end learning for vehicle control

**Deep learning:** machine learning approach that allows the computer to learn multiple levels of representation and abstraction from the data such as image, sound, and text

Artificial Neural Network is at the core of deep learning
Vehicle steering angle fit to ground truth (radian):

<table>
<thead>
<tr>
<th>Architecture</th>
<th>Base CNNs</th>
<th>L1</th>
<th>L2</th>
<th>L2 Fb (GT)</th>
<th>L2 Fb (PRE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abs Mean Std</td>
<td>0.140</td>
<td>0.085</td>
<td>0.081</td>
<td>0.069</td>
<td>0.073</td>
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<tr>
<td></td>
<td>0.193</td>
<td>0.121</td>
<td>0.113</td>
<td>0.097</td>
<td>0.102</td>
</tr>
</tbody>
</table>
Example demo

Input 16x32x3

Sensor Input

Perception/Localization

Planning

Control

8-3x3

Relu

Max 2x2

8-3x3

Relu

Max 2x2

Dropout 0.2

FC 50

Relu

FC 1

Output 1x1
Five eras of safety: are we there yet?

1950 – 2000
Safety/Convenience Features
✓ Cruise Control
✓ Seat Belts
✓ Antilock Brakes

2000 – 2010
Advanced Safety Features
✓ Electronic Stability Control
✓ Blind Spot Detection
✓ Forward Collision Warning
✓ Lane Departure Warning

2010 – 2016
Advanced Driver Assistance Features
✓ Rearview Video Systems
✓ Automatic Emergency Braking
✓ Pedestrian Automatic Emergency Braking
✓ Rear Automatic Emergency Braking
✓ Rear Cross Traffic Alert
✓ Lane Centering Assist

2016 - 2025
Partially Automated Safety Features
✓ Lane keeping assist
✓ Adaptive cruise control
✓ Traffic jam assist
✓ Self-park

2025+
Fully Automated Safety Features
✓ Highway autopilot

We may not be there yet, but...we are making progress: self-driving cars...according to NHTSA:

✔ Self-driving vehicles ultimately will integrate onto U.S. roadways in the coming years, as a result of technological advances and accompanying guidelines and best practices for policymakers.


✔ Supports further development of this important new technology.

✔ Calls for industry, state and local governments, safety and mobility advocates and the public to lay the path for the deployment of automated vehicles and technologies.
We may not be there yet, but...we are making progress: self-driving cars...according to NTSHA:

- DOT and NHTSA are already planning for 3.0.
  - A Vision for Safety is the newest version replacing previous guidance and offers a more flexible approach to advancing the innovation of automated vehicle safety technologies.
  - NHTSA wants to avoid impeding progress with unnecessary or unintended regulatory barriers to motor vehicles that have Automated Driving Systems (ADS) and unconventional designs, especially those with unconventional interior designs.
Renault, Nissan Motor, and Mitsubishi Motors announced up to $1 billion investment over five years in startups working on electric and self-driving cars, connectivity and artificial intelligence.

Toyota plans to embed Amazon’s Alexa voice-controlled digital assistant in some of its Toyota and Lexus models this year.

- Alexa of the feature will have the capability to give directions, read news, or even control Internet-connected home devices.

According to Ford, future relies not so much on cars as transportation systems.

- Systems-based approach, based on an operating system for transportation.
- Plans to start testing self-driving networks.

Transportation modes in cities include:

- Personal vehicles
- Ride-share services
- Bike-sharing networks
- Delivery services, buses and trains

According to Ford, all components of the system share information and streamline services:

- Key to this information sharing will be cellular vehicle-to-everything (C-V2X) technology, which will allow vehicles, stoplights, signs, cyclists and pedestrians to communicate quickly and securely.

At CES 2018, **Honda** came out with a new generation of robotic-related things - 3E Robotics Concept - both for transportation and human companionship

- With the Asimo robot and the Uni-Cub unicycle, Honda demonstrated it thinks beyond the humble automobile

And, in customary Japanese fashion, Honda makes a big effort to humanize these robotic devices, most notably with the 3E-A18 robot, designed to show “compassion to humans with a variety of facial expressions”
Waymo, a self-driving technology company that originates (2009) of Google parent Alphabet, performed world’s first fully self-driving ride on public roads in Austin, TX, in 2015.

In 2016 company became Waymo and introduced fully self-driving Chrysler Pacifica Hybrid minivans:
- First vehicle built on a mass-production platform with a fully-integrated hardware suite
- In 2017 Waymo invited residents in Phoenix, AZ to join a public trial of its self-driving vehicles

Waymo has surged past legacy car companies like Ford, Daimler, and Renault Nissan to grab No. 2 spot in Navigant Research annual autonomous driving scorecard:
- General Motors is still in the lead, but Waymo is close second, despite its complete inability to manufacture a car at scale.

Thank you!