Localizing Ground-Penetrating Radar Deep Dive

Byron M. Stanley

July 12, 2017
What problem is being solved by Autonomous Vehicles?

- **US Drivers:**
  - Over 3,000,000,000,000 miles driven each year
  - 35,000 fatalities per year
  - Per 100M miles driven
    - 180 crashes
    - 75 injuries
    - 1.1 fatalities
  - Over 53% fatalities due to road departures

- **WorldWide**
  - Over 1,250,000 fatalities per year
  - Over 54,000,000 injuries per year

What problem is being solved by Autonomous Vehicles?
How Are Autonomous Vehicles Solving the Problem?

Advanced Driver Assist Systems (ADAS)

- Hazard Recognition
- Lane Departure Warning
- Parking Assistance
- Adaptive Cruise Control
- Blind Spot Detection
- Fatigue Warning

Sensor Suites Enable ADAS and Autonomous Capabilities

- GPS/INS
- LIDAR
- Cameras / ADAS LIDAR
- Odometry & Ultrasonic Sensors
- Processor
- RADARs

Levels of Automation:

- Level 0: No Automation
- Level 1: Driver Assistance
- Level 2: Partial Automation
- Level 3: Conditional Automation
- Level 4: High Automation
- Level 5: Full Automation

Human Control & Responsibility

Vehicle Control & Responsibility

Sources: The Economist

How Close Are We to Zero Accidents?

“Level 0, 1, & 2” Autonomous Systems

Humans: \[ \frac{1 \text{ reported accident}}{497,000 \text{ Miles}} \]

- 40% reduction in rear-end collisions
- DOT considering mandatory inclusion

Forward Collision Avoidance

“Level 3 & 4” Autonomous Systems

Waymo: \[ \frac{1 \text{ safe operation disengagement}}{7,700 \text{ Miles}} \]

California 2016 Disengagement Report

Testing in generally benign conditions

Lane-keeping

Car & Driver 50 Mile Test Course

<table>
<thead>
<tr>
<th>Car</th>
<th>Miles per Disengagement</th>
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<tbody>
<tr>
<td>BMW</td>
<td>1.5</td>
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<tr>
<td>INFINITI</td>
<td>1.0</td>
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<tr>
<td>MERCEDES</td>
<td>2.0</td>
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<tr>
<td>TESLA</td>
<td>1.5</td>
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https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/testing
Challenges: Why aren’t we there yet?

Navigation in Complex & Dynamic Environments

Human Supervision & Reaction Time

Perception

Localization

Human "Supervisor" …

ZZZ……!
The Localization Accuracy Challenge

Total margin before vehicle departs lane
- Car: 0.35 m to 0.95 m
- Truck: 0.05 m to 0.55 m

Autonomous Vehicle Localization Sensors

Coarse

- GPS

Fine

- Lidar
- Camera
- Inertial (IMUs)
- Odometry
- Radar

http://mappingignorance.org/2014/04/07/one-way-googles-cars-localize/
http://www.planetiq.com/why-planetiq/
http://www.automotive-eetimes.com/content/mems-inertial-sensors-provide-equilibrium-sense-your-car/page/0/2
http://www.homemade-wheelie-bar.com/
Challenges of Reliable Optical Localization

Limited or changing features

Covered Surfaces

Surface feature changes

Obscuring conditions

Interference / Blinding

Typical autonomous vehicle sensor suite is challenged by a variety of adverse conditions
New Concept: Localization with Ground Penetrating Radar

- Subsurface environment is favorable for tracking
  - Richly featured with soil strata, rocks, pipes
  - Stable over long periods

- Employ Ground Penetrating Radar (GPR) to “image” 3D subsurface features
  - Weather and dust are effectively transparent
  - Energy directed into ground, i.e. difficult to deny, interfere
  - No moving parts

Novel Ground Penetrating Radar localization technique provides robustness
Outline

• Introduction to self-driving vehicles
• Localizing Ground Penetrating Radar (LGPR) concept & potential
• LGPR technology, challenges & results
• The way forward
## Alternate Localization Method Comparison

<table>
<thead>
<tr>
<th>Condition</th>
<th>GPS/INS</th>
<th>Camera</th>
<th>LIDAR</th>
<th>HD Radar</th>
<th>LGPR</th>
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<tbody>
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<td>Contested Spectrum (Blind, jam, interfere)</td>
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<td>Subsurface Changes</td>
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**Lanekeeping Ultimate Goal:** 
<1 major failure per 3 trillion miles driven (or better)

**Current systems:**
1 failure per 1K to 100K miles driven in generally benign conditions.

**Orders of magnitude improvement likely requires fusion of new sensor.**
LGPR Potential: Robustness & Maps

All-Condition Lane-Keeping

Current Autonomous Vehicles  Localizing GPR

Realtime Infrastructure Maps

Locate Utilities  Bridge Failures

Road State

Probability of Two Independent Errors:

\[ P(A \& B) = P(A) \times P(B) \]
LGPR Snow Demonstration

https://www.youtube.com/watch?v=rZq5FMwi8D4
Outline

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Rapid Prototype & Test - Highway Testing Results

- **Test Conditions**
  - 1.6 km track on public highway
  - Speeds 10 mph to 60 mph (16 km/h to 97 km/h)
- **“Truth” measurement**
  - Real-Time Kinematic GPS base station linked to an independent GPS/INS
  - Local ~2 cm level accuracy

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<tr>
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<th>Cross-Track Error (RMS)</th>
<th>Along-Track Error (RMS)</th>
<th>Total Error (RMS)</th>
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<tbody>
<tr>
<td>LGPR</td>
<td>4.3 cm</td>
<td>5.9 cm</td>
<td>7.3 cm</td>
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<tr>
<td>Differential GPS/INS (WAAS)</td>
<td>35.0 cm</td>
<td>41.7 cm</td>
<td>54.4 cm</td>
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Speed Test Performance Analysis

Typical Run Errors (LGPR and GPS/INS)

Overall LGPR Cross-Track Error

95.5%: 7.4 cm

68.3%: 3.3 cm

Success: Snow Testing Results
6cm Cross-Track Accuracy

Clear Baseline

Snow Tracking

Correlation

Track

Baseline
6 months – 12 km loop

- Average Temperature [deg F]
- Cumulative Precipitation [in]

- Normalized Distribution
- Correlation

- Samples Along Track

- Side Image

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BMS 7/13/2017

Lincoln Laboratory
Massachusetts Institute of Technology
Robustness & Broad Scale Utility

- A range of conditions to be tested
- Additional performance gains may be found:
  - Time series rather than single sweep correlations
  - High correlation matches not needed at 126Hz
  - Alternate algorithms
- Design of a low cost, mass produced system
The LGPR Mapping Vision

1. LGPR Commercialization
   - Development, Technology Transfer, & Licensing of MITLL Technology
   - Auto OEMs & Suppliers
   - GPR Manufacturers
   - Map Byproducts Drive Mapping
   - Reduced Accident Rate Drives Adoption

2. Map & Data Collection
   - Dedicated Vehicles
   - Modify Existing Infrastructure
   - Crowdsourcing

3. Map & Data Fusion
   - Users Record Changes in Features
   - Upload Data
   - Improve Maps

4. Map & Data Updates
   - Package feature updates
   - Distribute & Download Data
   - Improved Navigation

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Road to Low Cost LGPR

Cost Per Sensor

Prototype Units

Design for manufacturing

$1K-$3K / Unit

ASIC & Mass Production

$200-$300 / Unit or less
How to Engage

Partnerships and Technology Transfer / Licensing

• Partnerships / CRADA’s
  – rapid risk reduction
  – collection of key metrics
  – proprietary data collections
  – inventing new concepts with exclusively licensed patents
  – options to work with commercial partners

• Technology transfer & Licensing
  – immediate transfer of technology and related support / licensing.
  – Enabling direct testing and use of technology

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Reference Material

- **Youtube Video:**
  [https://www.youtube.com/watch?v=rZq5FMwl8D4](https://www.youtube.com/watch?v=rZq5FMwl8D4)


  [https://www.google.com/patents/US8949024](https://www.google.com/patents/US8949024)

- **Press Release:**
Key Results from the ITF - OECD Roundtable on Truck Automation

Dr. Tom Voege, Policy Analyst
International Transport Forum

Automated Vehicle Symposium AVS, July 2017, San Francisco
Breakout 6: Trucking Automation - Key Deployment Scenarios
The International Transport Forum of the OECD

Think Tank

Annual Summit

Intergovernmental Organisation

Moving Freight with Better Trucks

Research Report
Related recent ITF-OECD work

Roundtable Commercial Vehicle On-Board Safety Systems
www.itf-oecd.org/commercial-vehicle-safety-systems-roundtable

+ 

CPB Project Data-led Governance of Road Freight Transport

Managing the Transition to Driverless Road Freight Transport
Roundtable Overview

• Chair: Peter Sweatman, CAVita
• Location: USDOT, Washington D.C.
• Date: 5-6 January 2017
• Discussion Papers:

3. Mårten Blix, Research Institute of Industrial Economics, “Structural Change and Freight Transport Labour Market”
Key Issues

• What specific technologies for automation exist, covering platooning and full automation?
• What are specific implications of the technology options on infrastructure and human factors?
• How can such a system interact with manually operated passengers cars and trucks?
• How can potential wider societal and economic benefits be locked in, without additional risks?
• How do these systems need to be regulated, driven by industry or governments?
• What are the policy implications, how are liability, security and privacy concerns being addressed?
1. Autonomous trucks are likely to be the first use case of AV technology

- Long distance road freight make extensive use of motorways, less complex environment
- AV may achieve safe commercial operation on motorways earlier than on other roads
- Negative labour impacts of higher levels of automation should not be understated
- Opportunities for carriers and consumers to benefit from substantially lower costs
- Thus substantial incentives for long distance road freight to be the first use case for AVs
2. Harmonised regulation is more important for autonomous trucks than other AVs

- Across jurisdictions, both subnational jurisdictions within countries and international borders
- Susceptible to multiple regulatory frameworks applying to a single trip
- Could result in cross-border freight operators needing multiple on-board systems in vehicles
- The existing work within relevant bodies to harmonise regulations needs to accelerate
- Otherwise risk of losing some of the benefits that autonomous trucks could provide
3. Existing regulations can accommodate AV technologies up to a point

- Because technologies up to SAE 2 assist rather than replace drivers, existing frameworks are well placed to accommodate them

- Existing road rules, vehicle standards and type approval processes can all deal with this level of automation relatively well

- This provides a short period in which regulators can obtain further information before needing to regulate higher levels of automation
4. **Existing regulations can be stretched further to accommodate higher level AVs**

- Concepts such as the “driver” and “control” of a motor vehicle are central

- Assumes human in control, sometimes implicit and not explicit, creates room for interpretations

- Originally designed for human, the term “driver” could include multiple drivers or software

- Existing regulations can accommodate technology up to SAE level 4, albeit imperfectly
5. There are advantages to stretching existing regulatory frameworks

• Consistent with industry views preferring adapting existing regulation over creating new frameworks locking in a standard that is too high or too low

• Stretching is a relatively easy mechanism by which to ensure that automated vehicles conform to the same norms as human driven vehicles

• Interpreting existing regulations can avoid more advanced AV technologies being held back by a lack of progress in regulatory reform
6. Stretching existing regulatory frameworks has its disadvantages and limits

• Stretching the interpretation of legislation of regulations is a blunt instrument

• Not specifically for regulating autonomous trucks, as a result unintended consequences are likely

• Broad interpretation would see SAE level 4 technology legal to operate on public roads today

• Despite safety concerns about technologies and potential political backlash in case of accidents
7. Especially for trucks automation will create disruptive employment issues

• Substantial labour impacts are likely to arise as a result of advanced AV technology, particularly in the road freight sector

• Substantial job losses amongst drivers, within a decade, job losses in the order of 1 million people in each of Europe and North America are possible

• Unlike in other circumstances that have occurred previously, drivers displaced by automation may struggle to find alternative employment
8. Government interventions affecting speed of introduction and support to drivers

• Establishing a temporary transition advisory board to advise governments on these strategies
• Permit system to influence speed of introduction of AV technology and the associated job losses
• Economy-wide support of underemployed drivers such as universal income policies
• Industry specific support consistent with good practice for general unemployment support
• System to be funded by the main beneficiaries of the advanced AV technologies
9. Potential for data-led governance of the road freight sector generally

• Increasing gap between policy goals and the regulation actually implemented

• The effects range from undesired outcomes not originally foreseen to enforcement challenges

• Clear potential of data-driven approaches for regulating and enforcing road freight transport

• More targeted, flexible regulatory frameworks and more efficient enforcement mechanisms possible
10. Specific challenges for data-led regulation of the road freight sector generally

• Leveling the playing field
  - Technology readiness
  - Policy approaches
  - Economic development

• Need to shorten
  - Implementation times of technologies and systems
  - Time lag of policy and regulatory responses

• Additional issues due to innovation requiring new roles and responsibilities of stakeholders
11. Recommendations for data-led regulation of the road freight sector generally

- Embrace the concept of data-led policy making and consider move towards implementation of innovative data-driven regulatory approaches
- Data handling and processing requires cross-sectoral approaches, using new technologies, systems, and developments in data science
- Wider and more unstructured big data sets might be less applicable (big data)
- Automation of road freight vehicles is likely to be a game changer for data driven policy
Thank you for your attention!

www.itf-oecd.org/commercial-vehicle-safety-systems-roundtable

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