Vehicle to Pavement Passive Sensing for AV Lateral Position Detection

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• PhD Student working on the project - Sachindra Dahal
  • Papers
    • Dahal, S., Roesler, J., (2020). Cracking Patterns and Properties in CRCP with Internal Curing and Active Cracking. (Submitted: Transportation Research Record)
    • Dahal, S., Roesler, J., (2019). Passive Sensing of Electromagnetic Concrete for Lateral Vehicle Positioning. (Accepted: 12th International Conference on Concrete Pavements)

• Award
  • Intelligent Transportation Society (ITS) Michigan Scholar Award. – 26 February, 2019
Autonomous Vehicles (AVs) have arrived!

Driver/passenger safety

Roadway capacity

Improved mobility

Elderly, disabled, and youth

Traffic congestion

Fuel consumption

The New York Times

Despite High Hopes, Self-Driving Cars Are ‘Way in the Future’

Ford and other companies say the industry overestimated the arrival of autonomous vehicles.

Driverless Cars Arrive in New York City

Six autonomous cars will shuttle passengers around the New York Navy Yard for free.

Driverless efforts look past engineering to the difficult business of acceptance.

Who’s winning the race to build self-driving cars?

The Philadelphia Inquirer

Uber approved to resume autonomous car tests in Pittsburgh
Roadway Centerline Miles in USA

- Total Rural road (miles) = 2,933,528 (~70%)
- Total Urban road (miles) = 1,181,068 (~30%)

- Urban Roadway Distribution:

<table>
<thead>
<tr>
<th>Roadway Functional Classes</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interstate</td>
<td>1.5</td>
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<tr>
<td>Other Freeways &amp; Expressways</td>
<td>1.0</td>
</tr>
<tr>
<td>Other Principal Arterial</td>
<td>5.4</td>
</tr>
<tr>
<td>Minor Arterial</td>
<td>8.8</td>
</tr>
<tr>
<td>Major Collector</td>
<td>10.2</td>
</tr>
<tr>
<td>Minor Collector</td>
<td>1.3</td>
</tr>
<tr>
<td>Local Roads</td>
<td>71.8</td>
</tr>
</tbody>
</table>

(FHWA, 2020)
How do Connected & Autonomous Vehicles work?

Automated

Sense → Plan → Act

Connected

DSRC / Cellular-based

V2X → V2V / V2I / V2P
How do AVs work?

Different types of sensors.

- Camera
- RADAR
- LIDAR
- GPS
- Ultrasonic sensors
How do AVs work?

Plan vehicle movement.

• Computer Vision
• Machine Learning
• Path planning algorithm

Sense  Plan
How do AVs work?

Execute the command.

- Engine
- Steering
- Breaking

Sense  Plan  Act
How do AVs stay in lane?

GPS
• Coordinates from satellite

Camera
• Computer vision to find lane

Sensor fusion ➔ GPS + Camera (+ Lidar + Existing maps)
Use redundant information to predict better
What is the problem with existing system?

• Improper lane marking
• Bad weather (snowfall, fog, and rainfall)
  • Lane markings not visible ➔ Camera
  • Signal worsen ➔ GPS

• 33 states w/ 10+ inches of snow annually.  
  (Rutgers University, 2020)
• 60% of US covered in snow in Feb-2019.  
  (NOAA.gov, 2019)

Weather independence needed for large scale AV deployment.
How is the weather problem dealt with today?

Past Attempts:

- 3D maps + camera + GPS in snow/fog. (Belaroussi et. al, 2011)
- Remove rain/snow by different filtering methods. (Köylüoğlu and Hennicks, 2019)
- Lidar data pattern in snow and wet condition. (Alidibaja, 2016)
- Transponder embedded in road. (Houdali et. al, 2014)

Problem:

- Computationally expensive. Not real time.
- Does not eliminate snow. Not real time.
- Extremely complex lidar pattern in snow. Not real time.
- Electronics component in pavement. Require power and maintenance.
DSRC and Cellular-based approach

• Use wireless protocol or cellular network.

• Provide crucial information to driver.
  • Warning of potential crash.
  • Vehicle information (speed, acceleration, heading, brake status, path history, path prediction, etc.)

• 360 degree of awareness and create network of vehicles

Source: (Qualcomm, 2020)
Current V2I system

- V2I research focuses on:
  - Roadside units (RSUs)
  - Traffic controller unit

- Road is the biggest infrastructure and could be used to expand communication with vehicles.
  - Passive or active

Source: (Kakkasageri and Manvi, 2014)
Past attempts for vehicle-pavement communication

- Discrete magnetic marker @4 ft. (Chan, 2002)
- Magnetic tape with alternating North/South pattern. (Bajikar et al., 1997)

Need:
- Known magnetic model.
  - Traffic broke magnet → changing pattern from known model
  - Sensor “missed” reading magnets as a result
- Background noise prior to marker installation.
Are the current roads smart enough?

- **NO!** Pavement currently not designed to communicate with AVs.
- Create a unique and repeatable signature that AV can identify accurately
  ➔ **PASSIVE SENSING**
  - Strategic modification of the roadway electromagnetic properties
    ➔ changing lane markings or pavement material properties
Proposed passive sensing solution:

• Create an electromagnetic signature of the pavement that is standardized for AVs.

How?

• Strategic positioning of electromagnetic construction materials, e.g., steel fibers or steel slag aggregate in pavements.
  • During new construction or retrofitting.

• Establish AV to pavement interaction.
  • Weather independent.
Passive Sensing: working principle

• Material that changes electromagnetic property at desired location.
  • How? → Addition of metallic particles in the concrete or asphalt.

• Metals in general increase electric conductivity,
  i.e., allow current to flow more easily
Induction-based eddy current method

- Eddy current → Induced in conductor under changing magnetic field.
Magnetic field strength at target

• Magnetic field (H) decreases with distance of target from coil.
• \( H_{\text{at target}} = \frac{2nI r^2}{(r^2+z^2)^{3/2}} \)
  - \( I \rightarrow \) current
  - \( n \rightarrow \) number of turns
  - \( r \rightarrow \) radius of coil
  - \( z \rightarrow \) target distance from coil

• Lower H induces lower eddy current.

Coil height and radius matters.
Eddy Current sensor in lab

• Alternating magnetic field using 10-inch diameter search antenna.
• Frequency: ~ 200 Hz.
Laboratory test frame setup

- Aluminum frame with sensor
- Motorized setup
  - Drives sensors/coil at constant speed above slab.
Sample preparation

• Notched concrete slab
  • 1 inch x 1 inch
  • 2 inch x 2 inch
  • 3 inch x 3 inch

• Prism
  • Notch dimension

• Notched slab → Normal concrete
• Prism → concrete w/ EM material at various dosages

Scan from 5” - 7” (12-18 cm) above the slab to detect signature.
Surface condition of slab

• Normal ➔ notched slab surface - dry (nothing).
• Adverse ➔ surface material in plastic container above notched slab.
  • 0.5-inch, 1 inch, 2 inch ➔ three severity levels

• Water
• Ice and snow
• Sand
Eddy Current Results – steel fiber volume

- Passing the coil transversely over the slab

- Signal strength
  - High signal above the EM signature.
  - Depends on lateral position of sensor coil.

Source: (Dahal and Roesler, 2019)
Eddy Current Results – Coil Height

• Signal strength depends on height/distance of coil above the signature.

• As the coil height increases above the surface, signal decreases.

Source: (Dahal and Roesler, 2019)
Eddy Current Results – Notch dimension

• Signal strength depends on the size of the notch dimension.

• Larger notch size has higher signal compared to smaller.

Source: (Dahal and Roesler, 2019)
Eddy Current Results – Water and Ice

- Clear signals observed even when the slabs are imposed with adverse conditions.
- 2 inch (5.1 cm) of standing water and ice on top of the slab.
- Ice did not attenuate signal.
  - Low dielectric constant.

Source: (Dahal and Roesler, 2019)
Eddy Current: Summary

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<th>High</th>
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<tr>
<td>Coil Height</td>
<td>5 inch</td>
<td>6 inch</td>
<td>7 inch</td>
</tr>
<tr>
<td>EM prism size</td>
<td>3.5 inch</td>
<td>2.5 inch</td>
<td>1.5 inch</td>
</tr>
<tr>
<td>Steel Fiber %</td>
<td>1%</td>
<td>0.75%</td>
<td>0.50%</td>
</tr>
<tr>
<td>Surface Water</td>
<td>0 inch</td>
<td>1 inch</td>
<td>2 inch</td>
</tr>
<tr>
<td>Surface Ice</td>
<td>0 inch</td>
<td>1 inch</td>
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- Signal attenuated most by: Prism size, Sensor height, Fiber content.

- Factors can be controlled in design

Source: (Dahal and Roesler, 2019)
Eddy Current: Summary (2)

**Signal Attenuation Level**

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- 2” water attenuated signal by 23%.
  - Still easily detectable.
- Ice did not attenuate signal.
  - Low dielectric constant.

Source: (Dahal and Roesler, 2019)
Details about eddy current sensor tradeoffs

- Large diameter coil
- More winds on coil
- Reduced height of coil over the slab
- Higher conductive material
  - Any metal can be detected but geometry of target material matters
Field test of similar concept – Three Paths

- Centerline
- Offset
- Meandering
Camera vs Electromagnetic

- Even when lane marking is not visible, EM signature is detectable.
Conclusion

• AV interaction w/ pavement through passive sensors can assist in AV lateral position detection and maneuvering
  • Complements current AV sensors

• Strategic modification of electromagnetic material in pavement
  • Creates an EM signature that AVs can detect for lateral maneuvering
  • Functions during adverse weather conditions for lateral position

• Pavement infrastructure can be exploited to increase reliability of AV lateral position in adverse weather conditions.
Reference

• Dahal, S., Roesler, J., (2019). Passive Sensing of Electromagnetic Concrete for Lateral Vehicle Positioning. (Accepted: 12th International Conference on Concrete Pavements)