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
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>
</tr>
<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
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 w/ today?

Past Attempts:
- 3D maps + camera + GPS in snow/fog. (Belaroussi et. al, 2011)
- Remove rain/snow by different filtering methods. (Köylüoglu 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 $\rightarrow$ Induced in conductor under changing magnetic field.
Magnetic field strength at target

- Magnetic field (H) decreases with distance of target from coil.
- \( H_{\text{at target}} = \frac{2nIr^2}{(r^2+z^2)^{3/2}} \)
  - 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.

Steel Fiber Reinforced Concrete Beam
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)
what is steel content?
Roesler, Jeffery Raphael, 9/29/2020
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)
what is snow?
Roesler, Jeffery Raphael, 9/29/2020
Eddy Current: Summary

### Signal Attenuation Level

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<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>
<td>2 inch</td>
</tr>
</tbody>
</table>

- 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

<table>
<thead>
<tr>
<th>Source</th>
<th>Normalized signal with respect to high level (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil Height</td>
<td>100.0  61.9  23.9</td>
</tr>
<tr>
<td>EM prism size</td>
<td>100.0  74.5  11.8</td>
</tr>
<tr>
<td>Steel Fiber content (%)</td>
<td>100.0  74.5  11.8</td>
</tr>
<tr>
<td>Adverse Condition: Water</td>
<td>100.0  32.8  26.4</td>
</tr>
<tr>
<td>Adverse Condition: Ice</td>
<td>100.0  100.5  102.7</td>
</tr>
</tbody>
</table>

- 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)


