Pavement Markings Guiding Autonomous Vehicles – A Real World Study

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Problem Statement

At present, it’s unknown what factors in pavement markings are important to autonomous driving machine vision equipped vehicles.
Questions To Be Answered

• How does pavement marking
  – Retroreflectivity
  – contrast ratio
  – width
• affect the performance of machine vision?
• Are the key pavement marking factors different in a day versus night scenario?
• Are the key pavement marking factors different in a dry versus wet scenario?
Desired Outcome

If we can answer these questions, pavement markings can be engineered and applied in such a way that autonomous driving machine vision equipped vehicles will perform in a safer and more reliable manner.
Phase 1 Questions

• How far out in front of the vehicle does the machine vision system “look”?
• How large is the window of the machine vision system?
• Do these parameters change with vehicle speed?
• Do these parameters change in day versus night?
Test Method

• A test vehicle was equipped with a machine vision system.

• The system was modified such that it could be run in a static mode with varying simulated speeds.

• The system was tested in a static environment with consistent parameters (lighting, pavement retroreflectivity, etc). By placing retroreflective pavement marking panels in the view window
Phase 1 Results

• The machine vision system tested “looks” out in front of the vehicle roughly 20-60 feet.
• The optimum distance is in the 25-45 foot range at a simulated vehicle speed of 35MPH.
• The optimum distance increases to roughly 25-55 feet when the simulated vehicle speed is increased to 70MPH.
• There appears to be no difference in terms of the window sizes or optimums in a day versus night scenario.
Phase 2 Questions

• How does the machine vision system perform against pavement markings of different retroreflectivity?
• How does the machine vision system perform against pavement markings and pavement surfaces that yield different contrast ratios?
Test Method

• The same system and test method used in the Phase 1 testing was used here.
• The simulated speed was kept at a constant 35MPH.
• Two different pavement surfaces (8 mcd and 25 mcd) were tested.
Phase 2 Results

- At night, marking retroreflectivity is the most important factor.
- Retroreflectivity contrast ratio was not a factor. (The results were almost identical when tested on 8 mcd pavement.)

Nighttime Window Testing
25 mcd Pavement
Phase 2 Results

During the day, marking retroreflectivity has little impact on machine vision performance.
Phase 2 Results

During the day, luminance contrast ratio (not retroreflectivity contrast ratio) is the most important factor for machine vision performance.
Phase 2 Night Retro

• Higher Retroreflectivity increased Lane Confidence
Phase 2 Results

During the day, luminance contrast ratio (not retroreflectivity contrast ratio) is the most important factor for machine vision performance.
Phase 3 Questions

• How does the machine vision system perform against pavement markings of varying width?

• How does the machine vision system perform against various pavement markings in a wet recovery scenario?
Test Method

- The same system and test method used in the Phase 1 & 2 testing was used here.
- The simulated speed was kept at a constant 35MPH.
- For the wet recovery testing, a bucket of water was poured on the markings at the start of the test.
- All testing was done at night.
Phase 3 Results

- A 6” wide yellow panel of lower retroreflectivity performs as well (or better) than a 4” wide yellow panel of slightly higher retroreflectivity in a dry scenario – 50% more area returning light
Phase 3 Results

- A 6” wide white panel of lower retroreflectivity performs as well (or better) than a 4” wide white panel of slightly higher retroreflectivity in a dry scenario – 50% more area returning light
Phase 3 Results

- A 6” wide white panel of lower retroreflectivity performs as well (or better) than a 4” wide white panel of higher retroreflectivity in a wet recovery scenario – 50% more area returning light.
Next Steps

- Perform additional static testing on varying marking widths and materials to further quantify the machine vision performance in both dry and wet conditions.
- Modify test system software to get an accurate correlation between the machine vision and mobile retroreflectometer data.
- Perform dynamic testing in various conditions to confirm the results obtained during static testing.
Questions?

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NCHRP 20-102(6)

• Road Markings for Machine Vision
• Objectives
  – develop information on the performance characteristics of pavement markings that affect the ability of machine vision systems to recognize them
  – provide data and recommendations that the AASHTO/SAE Working Group can use to quickly develop guidelines and criteria
Work Plan

• Kick-Off Meeting
• Review Policies & Machine Vision Technologies
• Identify Testing Conditions
• Conduct Closed-Course Testing
• Analyze Results
• Prepare Reports
Current Testing Requirements

• ISO 17361:2007
  – No requirements on types of road markings
  – Lane markings must be in good condition and in accordance with the nationally defined visible lane markings std
  – No requirements on the environmental conditions
  – Visibility range must be greater than 1 km

• NHTSA
  – High contrast and uniform pavement
  – Lane marking specifications adhering to MUTCD
  – Avoiding tests in inclement weather including rain, fog, snow, hail, smoke, or ash
Texas A&M RELLIS Campus
Markings (Level 1)
Markings (Level 2)
Markings (Level 3)
Markings (Level 4)
Markings (Level 5)
Test Markings (all 4-inch)
- Continuous white
- Continuous yellow
- Skip white
- Skip yellow
- Dotted extension white
- Raised retroreflective pavement markers
- Raised non-reflective pavement markers
- Contrast markings
Testing Conditions

• Daytime
  – Dry and wet conditions
  – High sun position

• Nighttime
  – Dry and wet conditions
  – With and without roadway lighting
  – Tungsten-halogen and LED headlamps
Field Data
ROAD MARKINGS FOR MACHINE VISION SYSTEMS

Joint Working Group
AASHTO and SAE International
Kick Off Meeting – February 25, 2016
Follow Up Meeting – June 1, 2016
Many Challenging Conditions

- Uniform road marking criteria
- Preventive pavement maintenance treatments
- Horizontal curves
- Roadway lighting
- Nighttime conditions
- Wet conditions
- Snow conditions
- Debris
- Poor marking removal
- Shadowing
Vehicle Machine Vision Interaction with Traffic Control Devices

Automated Vehicle Symposium 2016
Breakout Session #20: Physical Infrastructure, Work Zones and Digital Infrastructure

July 20, 2016
Toyota Motor Engineering & Manufacturing North America
Toyota Technical Center
Hideki Hada
Toyota’s Approach for Automated Driving

Human driver and vehicle systems support each other for safer and more efficient vehicular mobility.

Automated Highway Driving Assist
ITS World Congress (Detroit, 2014)

Driving Intelligence
Connected Intelligence
Interactive Intelligence

http://www.toyota-global.com/innovation/automated_driving/
Building Blocks for Automated Driving

Automation is an important piece for a better mobility

Cooperative Mobility

Cooperative Driving

Automated Driving

Connected Services

Foundation ADAS Technologies

Toyota Safety Sense
Lexus Safety System +

AHDA  Automated

V2X  Cloud

Vehicle & Pedestrian Pre-Collision System
Dynamic Radar Cruise Control
Lane Departure Alert Lane Keep Assist
Auto High Beam
On-Board Sensors for Automated Driving Systems

Automated driving system uses signals from ADAS sensors

Automated Driving On-Board Sensors

Driver Assist On-Board Sensors

Vehicle & Pedestrian Pre-Collision System
Dynamic Radar Cruise Control
Lane Departure Alert
Auto High Beam

Toyota Safety Sense
Lexus Safety System +

http://www.toyota-global.com/innovation/automated_driving/
http://www.toyota-global.com/innovation/safety_technology/toyota-safety-sense/
http://www.lexus.com/models/RX/packages#lexus-safety-system
On-Board Sensors for ADAS

Camera & radar are main sensors for current ADAS

LSS+ (Lexus Safety System +), TSS P (Toyota Safety Sense P)
Government-Industry Initiative to Deploy ADAS

On-board sensors will be more common in a near future

**September 11, 2015**
Initial AEB Announcement

**March 17, 2016**
AEB MOU Announcement

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**U.S. DOT to add automatic emergency braking to list of recommended advanced safety technologies in 5-Star Rating system**

NHTSA 45-15
Monday, November 2, 2015
Contact: Kathryn Henry, 202-366-9550, Public.Affairs@dot.gov

Technology helps drivers brake to avoid or mitigate rear-end crashes

WASHINGTON - The U.S. Department of Transportation’s National Highway Traffic Safety Administration (NHTSA) today announced that beginning with model year 2018, the agency will update its 5-Star Rating System to include automatic emergency braking (AEB) as a recommended safety technology, providing consumers with new information on technology with the potential to prevent rear-end crashes or reduce the impact speed of those crashes by automatically applying the brakes.

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**U.S. DOT and IIHS announce historic commitment of 20 automakers to make automatic emergency braking standard on new vehicles**

Thursday, March 17, 2016
NHTSA contact: Gordon Trowbridge, 202-366-9550, Public.Affairs@dot.gov
IIHS contact: Russ Rader, 703-247-1530

MCLEAN, Va. - The U.S. Department of Transportation’s National Highway Traffic Safety Administration and the Insurance Institute for Highway Safety announced today a historic commitment by 20 automakers representing more than 99 percent of the U.S. auto market to make automatic emergency braking a standard feature on virtually all new cars no later than NHTSA’s 2022 reporting year, which begins Sept. 1, 2022.
Several assessment programs are also accelerating deployment of on-board sensors for ADAS systems.
Target for ADAS Performance Confirmation

ADAS system performance is assessed against targets. But, creation of good target is a real science


Research into Evaluation Method for Pedestrian Pre-collision System


http://www.4activesystems.at/en/
Target Road for ADAS Performance Confirmation?

How do we vehicle performance against roads?
(it would be nice to see a standard road…)

Traditional Approaches
- Camera
- Road Map
- Test Drive
- Experience

New Opportunities
- V2X
- 3D Map
- Data
- Levels

V2X as an Additional Sensor for Automated Driving Systems

V2X DSRC Technologies are also in the market

Japanese: [Link](http://toyota.jp/technology/safety/itsconnect/)
English: [Link](http://www.toyota-global.com/innovation/intelligent_transport_systems/infrastructure/)
Safety enhancement with driving automation technologies

DRCC
Dynamic Radar Cruise Control

LTC
Lane Trace Control

Preview HMI

Driver Monitor HMI

Driver Assist:
On-Board Sensors

Lateral and Longitudinal Control

Two-Way Driver-Vehicle Interaction

Face Direction Detection

Steering Touch Sensor
Automated Highway Driving Assist – 2014 Demonstration

Infrastructure information for automation (map): an early alert about the road conditions where adequate support from the vehicle system may be limited.

**A: Left Merge Preview**
- An uncommon merge from left is ahead.

**B: Exit Only Lane Preview**
- The AHDA vehicle needs to exit the highway if remains in this lane.

**C: Unsupported Scene Preview**
- Difficult to see lane markings by camera.

**D: End of Highway Preview**
- The current highway ends.
Connected and Automated

Information from & about the road, traffic and other vehicles will enhance capabilities & performance of automated vehicle control systems.

V2X Communication

Automated Driving

Advanced Sensing

Digital Map

Data

Better Driving Experience

Toyota to Display New Map Generation System at CES 2016
http://corporatenews.pressroom.toyota.com/releases/toyota+map+generation+ces+2016.htm
Our goals are the same. We need each other. But… are we working together?

We have two sets of materials.

Vehicle Design

How should we set requirements for lane marker detection?

It is in Part 3 of MUTCD (90 pages). They are guidelines.

There are many faded lane markings. ("fix the road")

It is maintained based on our standards. ("make cars better")

Road Design

It is a good time for us to work together.
What Vehicles can “See”

Sensing technologies have been improving significantly.
(sample images found through Google search “sensor image on-board car”)

http://spectrum.ieee.org/automaton/robotics/artificial-intelligence/how-google-self-driving-car-works
http://www.4erevolution.com/volvo-drive-me/

http://autonomos-labs.com/research/
http://www.linleygroup.com/mpr/article.php?id=11437
What Vehicles may not be able to “See” sometimes

There are still areas for improvements.

It cannot see it if it is not there.

https://www.fhwa.dot.gov/publications/research/safety/13048/004.cfm

It may not see everything


It may not see it if it is hard to see.


It may see something even it is not there.

And, also it is very dynamic…

Lane Detection and Tracking (https://www.youtube.com/watch?v=BadCBN48ztY), Smartmicro 3DHD Automotive Radar (https://www.youtube.com/watch?v=ON97Bm-lKgE&list=PL52C8001562502C7D), Delphi Automotive Radar provided by AutonomouStuff (https://www.youtube.com/watch?v=OovcjSbxdBM)
Potential Areas for Collaborative Work

Personal thoughts…

Identify crash prevention countermeasures through crash causation and crash history studies?

Designate “auto drive capable” roads?

Avoid Smart Road – Smart Car Conflict

Joint Review of MUTCD?

Mapping Convention of Signs?

New Signs?


Better Roads and Better Vehicles = Better Driving

Connected and automated driving brings good driving experience.

On-Board Sensor → Collision Mitigation
Collision Avoidance → DSRC
Risk Mitigation → Risk Avoidance
Guarded Driving

Map, Data, and Other Technology Improvement

“Stress free driving”
“No confusion”
“Fun of driving”
“Nice to the others”
**Summary**

**Vehicle Technology:**
- Improvement of ADAS system availability and performance enables enhancement of Advanced Driving Support Systems (ADAS) toward automated driving.
- V2X and data/map will serve as additional sensors.

**Road-Vehicle Interaction:**
- Inter-industry dialogue is essential for:
  - Ensuring good performance of vehicle systems on public highways
  - Avoiding potential conflict between smart cars and smart roads.
  - Setting roadmaps toward deployment of new technologies.
  - Sharing know-hows for improving traffic safety
- Talk between industry associations may be most efficient.
  - Than all OEMs trying to talk to all states separately.
Dynamic Map Development in SIP-adus

Cross-Ministerial Strategic Innovation Promotion Program
Innovation of Automated Driving for Universal Services

July 20, 2016

Ryota Shirato

Member of System Implementation WG, SIP-adus
(Nissan Motor Company)
Scope of SIP-adus

(I) Development and verification of automated driving system

(II) Basic technologies to reduce traffic fatalities and congestion

(III) International cooperation

(IV) Development for next generation urban transport
Dynamic Map

Hierarchical structure of digital ‘Map’ layered by time frame

**Time frame**
- **Dynamic ( < 1 sec )**
- **Semi-dynamic ( < 1 min )**
- **Semi-static ( < 1 hour )**
- **Static ( < 1 month )**

**Linked layers**

- **Information through V to X**
  - surrounding vehicles
  - pedestrians
  - timing of traffic signals

- **Traffic Information**
  - accidents
  - congestion
  - local weather

- **Planned and forecast**
  - traffic regulations
  - road works
  - weather forecast

- **Basic Map Database**
  - Digital cartographic data
  - Topological data with unique
  - Road Facilities
Framework for Dynamic Map

Data Collection
- Public Agencies
  - Congestion
  - Accidents
  - Road conditions
  - Traffic regulations
  - Road signs
- GSI, Road Authorities
  - Structural data
- Private Sectors
  - Field survey
  - GNSS
  - MMS

Compilation as ‘Dynamic Map’
- Common database
  - Structured Database
- Dynamic Data
- Static Data
  - 2014 activity
  - 2015 activity

Service Operations
- Map database
  - Probe Data
    - Location
    - On-board sensing
    - Image
- Map Supplier A
- Map Supplier B
- Operation Service X
- Operation Service Y
  - Subscriber
  - Subscriber

Customization
- Structured Database
- Map database
- Probe Data
  - Location
  - On-board sensing
  - Image
- Alliance
Prototyping HD Static Map (2014)

Road Environment

Target Area

3D Measurement

Linked Objects
## Static + Dynamic Data Structuring

<table>
<thead>
<tr>
<th>Year</th>
<th>GIS Data Preparation</th>
<th>Dynamic Data</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>Prototyping HD Static Map</td>
<td>Use Case</td>
<td></td>
</tr>
</tbody>
</table>

### 2015

- **① Dynamic Map Structure**
  - Data Format (proposal)

- **③ Static Data Updating**
  - Updating Guidelines (proposal)

- **② Applying Dynamic Data**
  - Implementation Roadmap (proposal)

- **④ Dynamic Map Prototyping**
  - Requirement Definition (proposal)

### 2016 ~

- Nationwide Development
- Updating Scheme
- Verification
- Standardization & Globalization
- Operation Process

### Implementation of Dynamic Map

1. Showcase of Automated Driving in Tokyo
2. Automated Driving on various roads
Dynamic Map Structure

**Dynamic Data**
- Vehicle, Pedestrian, Traffic light: Point data
- Traffic jam, Traffic control info.: Line data

**Location Referencing**
- Section ID, Marker Point, Longitude & Latitude

**Digital Roadmap, Lane-level map**
- Road link, Lane link, Intersection area

**Virtual Features**
- Mapping from MMS data

**Real Features**
- Lanemark, Shoulder, Stopline, Crossing, etc.

**Static Data**
- $\pm 25\text{cm}$ Relative accuracy
Static Data Updating

Dec. 5, 2014 AM

Dec. 5, 2014 PM

Matching 2 layers

Cones
No Cones

Cones

Fences

Matching Boundaries
Guardrails

Matching
Applying Dynamic Data

Actual Situation

Applying Image

Expression by Point

Expression by Line

Marker Point

Lateral Position

Offset

Head Position

Tail Position

Length

Road link ID

Direction

Pedestrian

Work zone

Vehicle

Intersection

Lane Link

Road Link
Dynamic Map Prototyping - Viewer

Vehicle

Pedestrian

Work zone
Next Steps

• Applying Real Dynamic Data to Dynamic Map Structure
• Evaluation in Large Area
• International Standardization
Thank you for your attention!