Lane Guidance Systems for Rural Highway Maintenance

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Human-Centered Technology to Enhance Safety and Mobility

Disciplines from several colleges on 2 campuses including:
- Civil Engineering
- Computer Science
- Electrical Engineering
- Industrial Engineering
- Mechanical Engineering
- Policy and Public Affairs
- Psychology
- Law

...and many counties
Topics

- Technology that adapts to humans
  - Human centered design
  - Enhancing visibility; Lanekeeping assistance
  - Enhancing situation awareness
- Accuracy and DGPS
- Lane Level Digital ‘Maps’: … the new infrastructure
- Driving in narrow lanes: … bus-only shoulders
- Other applications: Reducing lane departure fatalities
Human Centered Technology for Driver Lane (Lanekeeping) Assist
Handling low visibility and staying in the lane

First prototype developed for snowplows operating in whiteout conditions
- Blowing snow even without snowfall
- Heavy snowfall

Why snowplows?

- Professional drivers operating under stressful conditions
- Need to be out there under terrible conditions
- At-risk driver population
- Early feedback for other apps

QuickTime™ and a YUV420 codec decompressor are needed to see this picture.
WTI Survey of Snowplow Operators

- 992 operators from Idaho, Montana, North Dakota, and Wyoming DOT’s.
  - 30% indicated that they lost sight of the roadway and shoulders 4-6 times during an average snowstorm.
  - 83% indicated that if a device existed that would allow for drivers to determine lane position, it would be very useful.
An Augmented Conformal Head Up Display

- By referencing the vehicle AND the driver’s eye position within an accurate digital map, one can accurately recreate the field of view from the driver’s eye perspective.

- System allows all lane boundaries and obstacles to be drawn and projected in real time on a virtual screen 30 ft. in front of vehicle (to reduce eye fatigue)
Vehicle Technologies

- GPS Antenna
- Forward Radar Sensors
- HUD
- Tactile Seat
- Haptic Steering Feedback Actuator

Vehicle Technologies

IT'S INSTITUTE
Intelligent Transportation Systems

UNIVERSITY OF MINNESOTA
Current deployment

- Deployed on Mn/DOT, Minnesota State Patrol, McLeod and Polk Counties, MVTA and Alaska DOT vehicles.
Not just snowplows …
Deployed in State Patrol Car
And buses: Sequence showing bus operating in narrow lane with adjacent truck
An Alaska Perspective: Snowpoles
The Snow is Plentiful
You Can’t Just Stop
Lane Assist Technologies: Enhancing Situation Awareness

- Vehicle Position and Orientation
  - Dual frequency differential GPS
- Geospatial Database (aka “Digital Map”)
  - Identification and location of fixed objects local to the road
- Obstacle Detection
  - Radar based sensing of mobile objects local to the road -> Location of roadside objects used to filter radar reflections from the side of the road.
- Warning systems
  - Algorithms to determine reliable trigger conditions for lane departure warnings while driving
- Human Vehicle Interface
  - Presentation of relevant information to the driver to assist with lane keeping -> visual, auditory, haptic steering wheel, vibratory seat (tactile) … Buzz the left or right buttock!
Driver Interfaces

How do drivers best receive relevant information?

HUD

Virtual mirror
Video of HUD (Approaching intersection)

QuickTime™ and a YUV420 codec decompressor are needed to see this picture.
DGPS: Signal Loss and Reacquisition of Signal

- Dual frequency models (first appeared 1999):
  - Submeter solution accuracy (50-70 cm).
  - [...] WITHIN one second of when the first DGPS correction arrives.
  - Within 10 seconds, down to 10 cm.
  - Within 30 seconds, accuracy down to 2 cm.
  - Latency: 20 millisec.; Rate: 10 Hz

- Multiple vendors offer product (since 2001), but not all necessarily meet dynamic accuracy performance req’ts
- First vendor claims 10 cm. correction signal available worldwide from satellites (2002)
Differential GPS Correction Sources:
Various Accuracies

- Ground-based:
  - NDGPS (US Coast Guard, Federal Railroad Administration; similar to Maritime correction stations located around the world)
  - Custom: Broadcast on FCC allocated public band frequency
  - Virtual reference stations (Mn/DOT – Trimble - U of MN partnership on VRS)
  - High Accuracy NDGPS (HA-NDGPS under development by FHWA)

- Satellite-based:
  - WAAS, EGNOS, NavCom, Thales, Omnistar
Dual Frequency Differential GPS

- Dual-frequency GPS receivers have ability to internally resolve ionospheric delay.
- Differential signal corrects for:
  - GPS satellite clock error
  - Ephemeris data error
  - Tropospheric delay
Hi-Accuracy DGPS Correction Signal Coverage in Minnesota
76 base stations
October 30, 2007

VRS Networks

- All 260 miles of I-94 corridor in MN covered
- 25 states have plans to set up VRS networks
- 12 states with operational VRS
- Minnesota first one to start
- Texas biggest network with 90+ base stations
Dynamic Evaluation of High Accuracy Differential GPS (Trimble MS-750)

- Experiments conducted at MnRoad facility
- Camera: Computer controlled shutter triggered to minimize latency
- GPS antenna mounted coaxially with camera image center
**Dynamic Accuracy: Aggregated Results**

**Trimble MS-750 Receiver (fix mode)**

<table>
<thead>
<tr>
<th></th>
<th>Mean Lateral Error (cm)</th>
<th>SD $[\sigma]$ Lateral Error (cm)</th>
<th>Mean Longitudinal Error (cm)</th>
<th>SD $[\sigma]$ Longitudinal Error (cm)</th>
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</thead>
<tbody>
<tr>
<td>Short baseline RTK</td>
<td>0.6</td>
<td>11.9</td>
<td>-3.3</td>
<td>4.4</td>
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<tr>
<td>Long baseline RTK</td>
<td>-0.04</td>
<td>8.2</td>
<td>-6.4</td>
<td>1.6</td>
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<tr>
<td>Short baseline VRS</td>
<td>-2.4</td>
<td>9.5</td>
<td>-5.2</td>
<td>1.4</td>
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<tr>
<td>Long baseline VRS</td>
<td>-0.2</td>
<td>9.5</td>
<td>-5.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

- Short baseline is 1 km from the base station, located at the HARN, MnRoad
- Long baseline is 15 km from the base station, located at the Rogers tower
Distribution of Lateral Errors: Difficult for a Skilled Human to Replicate

Technobus Lateral Error Distribution, 35 MPH Average Speed

Mean Lateral Error = -0.056 meter
Std. Dev = 0.13 meter
Lane Assist Modality: Haptic Feedback

Under current operations, drivers often like to use the guardrail to determine the extent of the drivable surface.

When curb is not there, can use DGPS, geospatial database, and steering actuator to provide “virtual curb.”

Steering wheel is actuated to feel like a curb when one is not there. Can create a detent or torque valley to identify the center of lane.

Seat with vibration actuators indicates “out of shoulder lane.”
Guardrails get Clobbered by Snowblowers and Plows
Thompson Pass and Valdez, Alaska: Dual Frequency Receiver with No Differential Correction

- Accumulated data represents ~ 22,000 points, simplified for visualization
- **Green:** > 6 satellites  
  **Blue:** 5 satellites  
  **Yellow:** 4 satellites  
  **Red:** < 3 satellites

Keystone Canyon
Thompson Pass snowplow route
Mile 18 (south end) to mile 45 (north end)
DGPS Correction Station at Divide
Keystone Canyon
Installation on Blower and Plow at Thompson Pass Station

Blower cab

Cab roof in plow
Installation at Deadhorse Airport
Q: Benefits?

DD: Wonderful when visibility is poor. It is like running on ‘autopilot.’ It is nice to have a ‘direction’ to get through nasty storms. Also, the front facing radar picked up a car that I would not otherwise have seen coming towards me in the wrong lane. I moved over and was able to avoid a head-on wreck by ‘whiskers’. During the previous winter that feature was turned off. I like it on since I do want to know where the cars are on the road.
Interview with Operator (8 winters experience at Thompson Pass)

Q: Can you operate more efficiently with it? Can you go faster?

DD: I am not computer literate, but this system is very user friendly – easy to use. I think it makes me more efficient.

When it is so bad out that I am using it, I am going very, very slowly (creeping along at about 1 mph). I am worried about drifts or a car stuck in a drift, so I can’t go faster.

The screen is surprisingly accurate. I follow the screen. I can follow a straight line much better with it.
Q: Are you now able to plow without it?

DD: Yes, but it is a great tool. It makes the job less stressful. I guess that I would say that it makes me feel safer. I wonder how we did it before we had the technology. I learned to rely on it.
Video through HUD on Minnesota Hwy 101 (Radar OFF)

Day time view to show accuracy of projected lane markings

QuickTime™ and a YUV420 codec decompressor are needed to see this picture.
Several Hundred Miles Digitized

- Memory efficient architecture reduces storage requirement, while allowing real time access (millisecond resolution)
  - One can “drive thru the data”
  - Sensors can access map data at same bandwidth as sensor acquisition

- Examples of memory requirements:
  - 67 miles of MN Hwy 7 includes
    - 220 mailboxes, 65 guardrails
    - 26 Jersey barriers, etc.
  - -> Only 1.5 MBytes

- More complex roads:
  - -> 14 miles/MB (MN Hwy 101)
  - Shown on right with blowups of two areas

- Methods developed to digitize in real time
Digital Maps (Geospatial databases): Where are we?

A: Today’s map
- Same accuracy (+/-10m) as commercially available maps today, but could still have straightforward content (features and/or attributes) added
- i.e., Accuracy and detail can provide “which road”

B: Today’s map +
- Today’s maps with significantly enhanced content (not necessarily more; could be less depending on appl’n) AND tighter accuracy
- ~1 order of magnitude improvement
- i.e., Accuracy and detail can provide “which lane”

C: Future maps
- New-generation maps with vastly greater content and much tighter accuracy
- ~2 orders of magnitude improvement
- i.e., Accuracy and detail can provide “where in the lane”
Cost and map data acquisition

- Cost is prohibitive unless new paradigm used.
- Significant institutional issues in getting required accuracy nation-wide.
- To accelerate high accuracy map detail acquisition in cost effective manner, must take advantage of state, county and municipal organizations entering data into nation-wide database at time of construction, maintenance, installation, etc.
- Approach leverages existing local DOT activities.
- Benefits accrue to many DOT functions, e.g. maintenance, asset management, etc.
## Total Cost and Time Frame to Map Minnesota and US Rural Road System

<table>
<thead>
<tr>
<th>Area – Number of Mapping Vehicles</th>
<th>Rural Road Miles Mapped</th>
<th>Equiv. Lane Miles Mapped</th>
<th>Time Frame (Years)</th>
<th>Total Capital Cost (USD)</th>
<th>Total Operating Cost (USD)</th>
<th>Total Cost per Year (USD)</th>
<th>Cost per Lane Mile (USD)</th>
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<tbody>
<tr>
<td>Minnesota – 1</td>
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<td>252,191</td>
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### Assumptions
- Map accuracy: 20 cm at one sigma, or better
- Data collection AND quality assurance: 30 weeks per year
- Does not account for inflation (Above in 2005 dollars)
- Does not account for multiple quantity price reductions
States and Counties as Source of High Accuracy Maps

- Paint stripers. Consider Minnesota:

  - Minnesota has 134,000 miles of public roads (1/2 gravel)

  - Mn/DOT stripes 12,300 center line road miles

  - Equivalent to 36,900 line miles (actual painted line, not including gaps)

  - Minnesota paints 24,000 line miles per year on average (5,600 line miles in the metro area alone)
Where is visibility a problem?

- Snowfall alone is not a good predictor of visibility.
- Must consider snow in combination with wind at the road surface as a predictor.

*Combined Winter Wind (average > 9.8 MPH) and Snowfall (> 24” Annually.)*
For more info on benefit analysis

- Sponsored as part of the USDOT Intelligent Vehicle Initiative (IVI) Specialty Vehicle Field Operational Test


- Copies at
  http://www.its.umn.edu/Research/ProjectDetail.html?id=2000037
Other Applications: Gangplowing and Platooning Buses
Vehicle-to-Vehicle Communications

Sample Operation:

- One vehicle receives its differential GPS correction from the base station and transmits it to the other vehicle.
- That vehicle sends back its corrected DGPS location.
- Additional robustness can be achieved using radar, LIDAR…
Urban Partnership Agreement: Minnesota’s Congestion Mitigation Initiative
Video:
Haptic Feedback Assist for Lane Keeping

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