Positioning Challenges in Cooperative Vehicular Safety Systems

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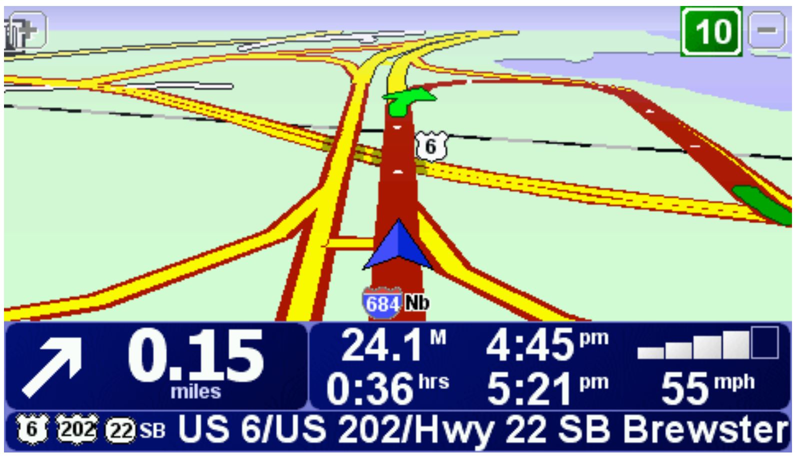
Positioning for Automotive Navigation

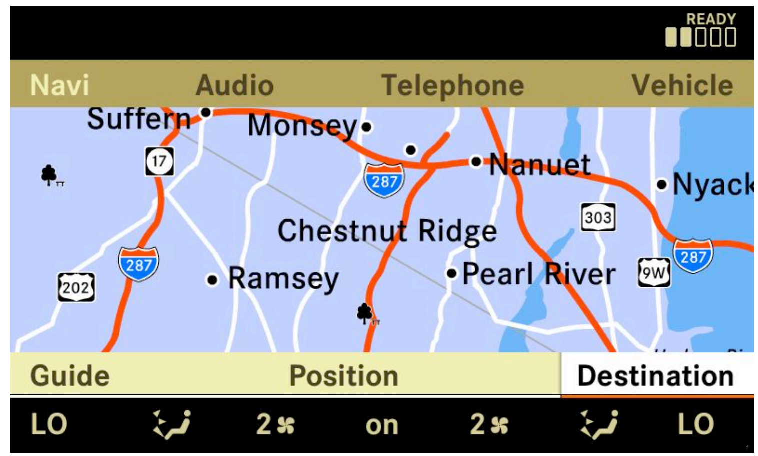
Personal Navigation Devices



GPS only

- L1 receivers, no differential corrections
- Not integrated with vehicle sensors
- Just coast the last speed and heading (sharp turns in inner city environments can throw system off)

Factory installed Systems

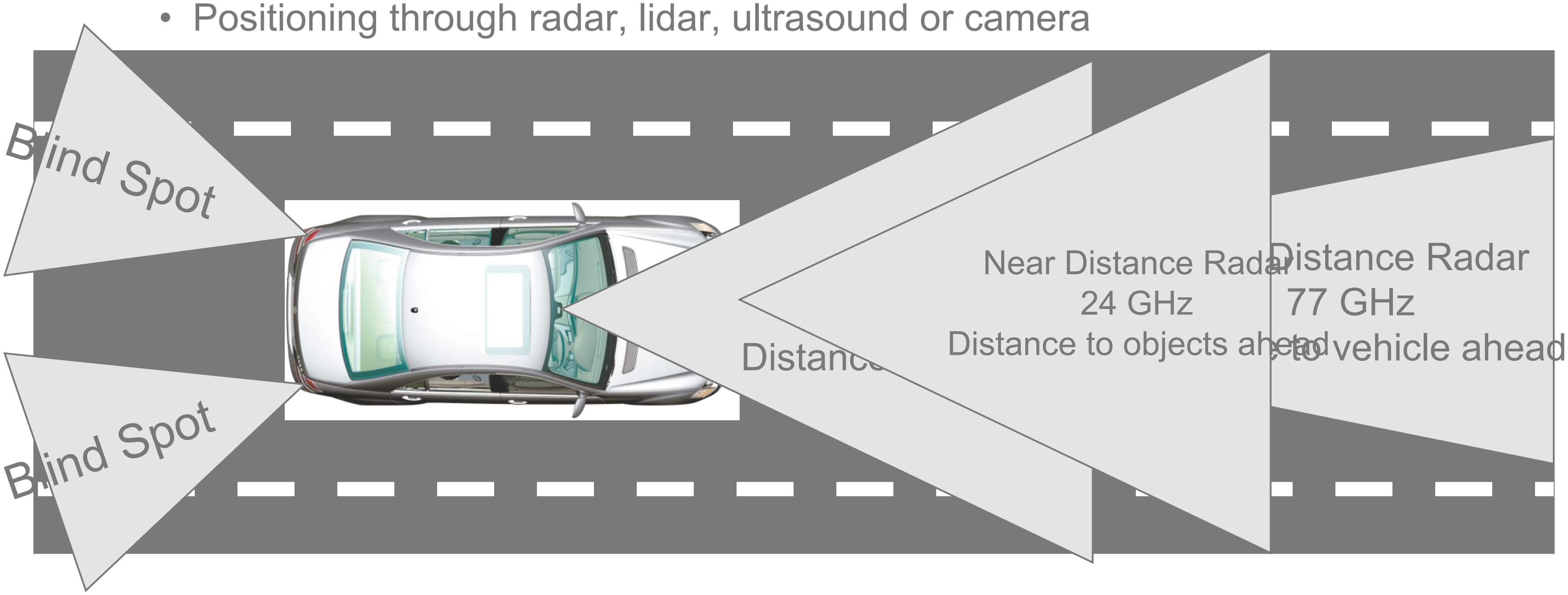


GPS and dead reckoning

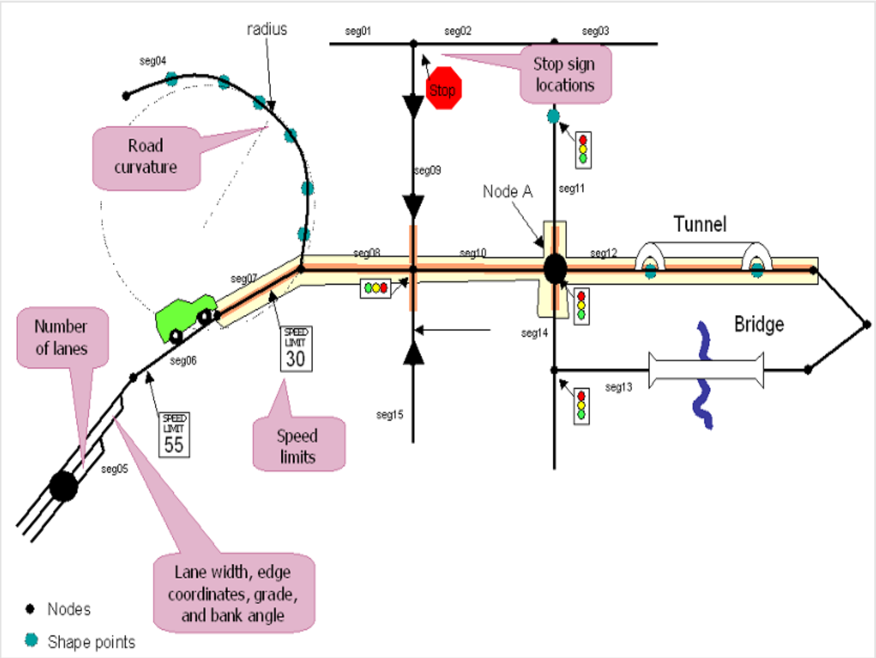
- Wheel Speed, Steering Wheel Angle, Yaw Rate and Map Matching
- Works well, even for longer outages (several minutes)
- Sufficient for navigation but not for safety

Current relative positioning for safety applications

- Most safety applications use some form of relative positioning
  - Currently the positioning used does not include GPS
  - Positioning is relative to perceived threat or lane
  - Positioning through radar, lidar, ultrasound or camera



Map and positioning based safety applications



Safety Applications (examples)

- Curve speed warning
- Stop sign violation warning
- Speed advisory
- Lane departure warning

Required information in the map

- Road curvature
- Precise lane geometries with 50 cm accuracy
- Stop locations at intersections

Some applications require sub-lane level accurate positioning and geometries

Map and positioning based safety applications

- Currently those maps only exist in experimental form and are not commercially available
- Highly accurate maps for large areas are difficult to generate and the cost is currently prohibitive
- Updating those maps is much more necessary, since the lane geometries are changing constantly
  - Intersections are reconstructed with new turn lanes added
  - Long-term construction sites with lane closures
  - Conversion of uncontrolled intersections into stop controlled intersections
  - Paint for the lanes shifts after reconstruction
- Vehicles do not need highly accurate maps on-board for the entire US
  - Small, local maps with required features can be sent to the vehicle as needed
  - Requires communications on the vehicle (cell phones, DSRC)

Communications based safety applications

- Applications use 5.9GHz Dedicated Short Range Communications (DSRC) to communicate vehicle and infrastructure status information
- Two basic types:
  - Vehicle-to-Infrastructure communication (V2I)
  - Vehicle-to-Vehicle communication (V2V)
- Systems use absolute positioning and relative positioning
- Maps are sent from the infrastructure to the vehicle
- Positioning based on GPS and dead reckoning

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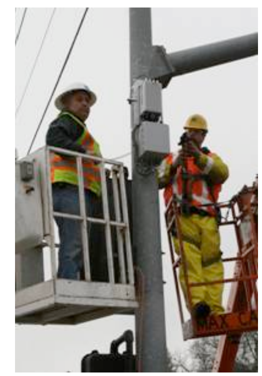
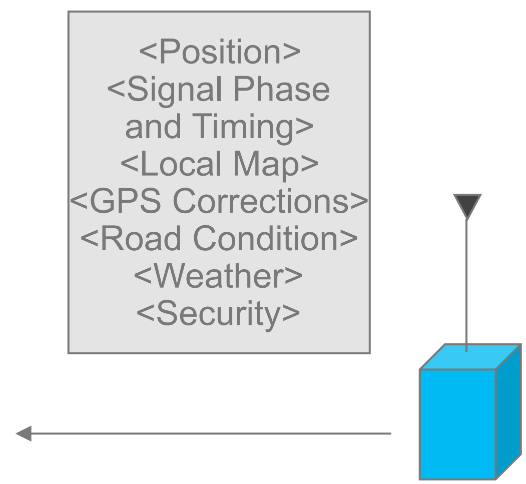
V2I communications based safety applications

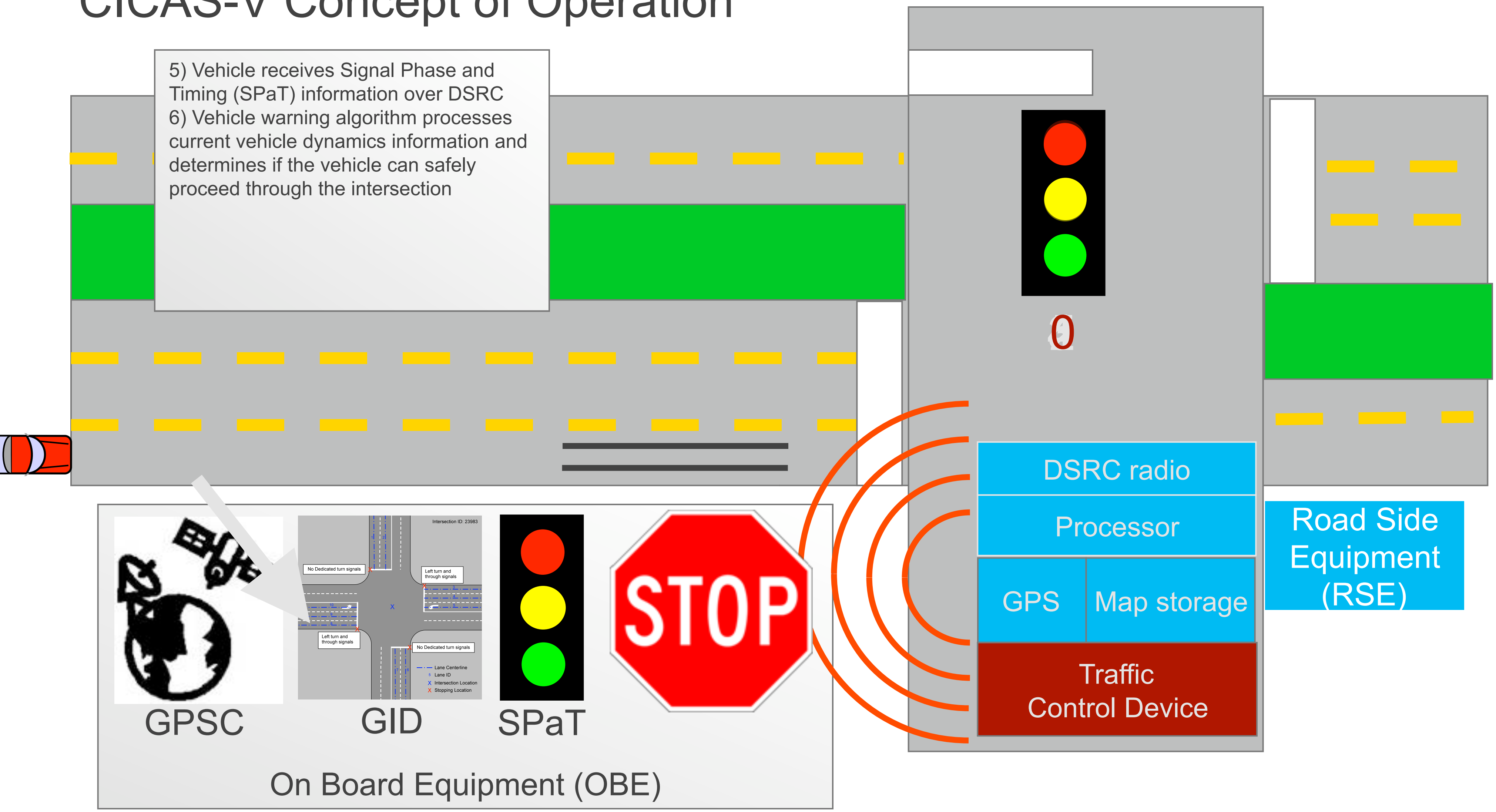
- Roadside Equipment (RSE) broadcasts info to vehicles through 5.9GHz DSRC
- Examples are
  - Cooperative Intersection Collision Avoidance Systems
  - Road departure warning
  - Danger zones, Speed limits
  - Weather based hazards
- RSE broadcast may include a local map as well as DGPS corrections





CICAS-V Concept of Operation

5) Vehicle receives Signal Phase and Timing (SPaT) information over DSRC
6) Vehicle warning algorithm processes current vehicle dynamics information and determines if the vehicle can safely proceed through the intersection



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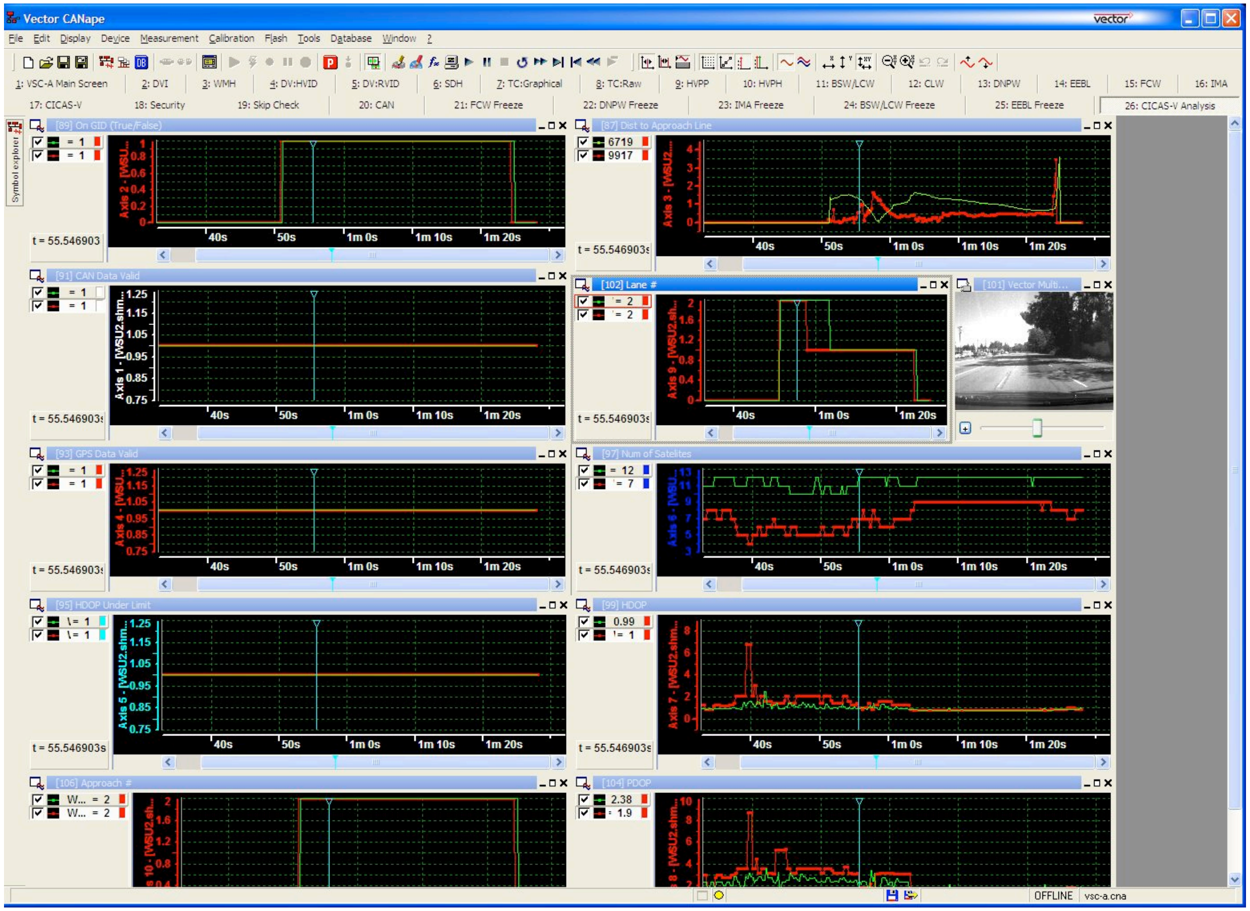
CICAS-V Positioning Needs

- Two levels of positioning accuracy
- WhichRoad for road level accuracy
  - Map and GPS errors < 5 m
  - Sufficient for stop sign controlled intersections and simple signalized intersections with no dedicated turn lanes
- WhichLane for lane level accuracy
  - Map and GPS errors < 1.5 m (half lane width)
  - Needed for intersections with dedicated turn lanes
  - Map accuracies should be around 10 cm so that error budget for positioning can be larger

CICAS-V DPOS Performance at 5th and El Camino

- High performance receiver is able to correctly determine lane
- Low cost receiver initially matches vehicle to wrong lane
- Receivers use WAAS for differential corrections
- Measurable difference in performance



RTK Performanc

Using Right Lane

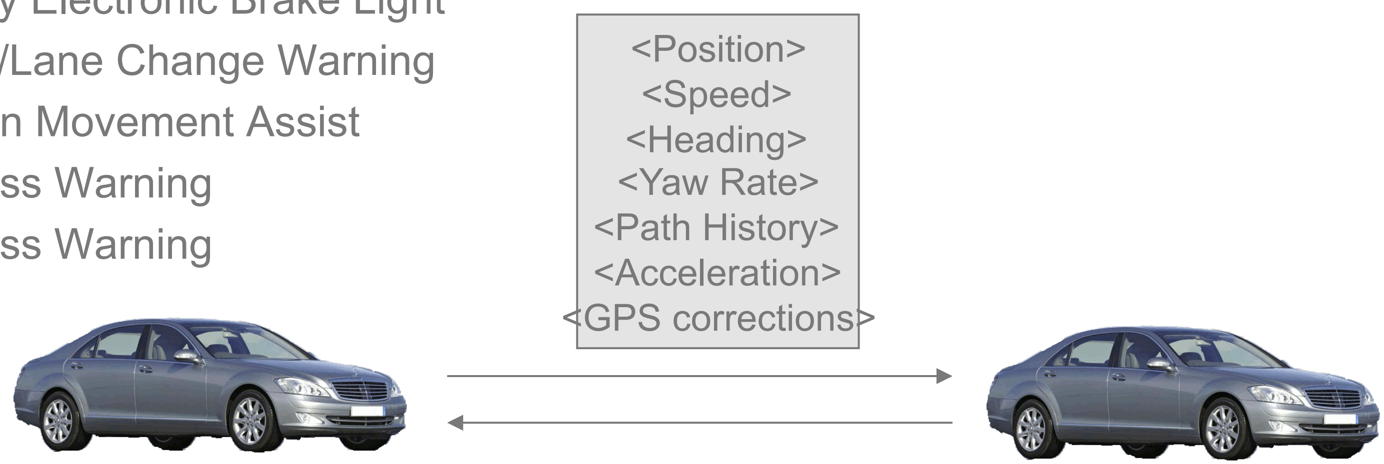
- Shows consistent WhichLane performance
- Accuracy <1m, usually around 50 cm or better

Changing Lanes to Go Through

Turning Left on to Inside Lane

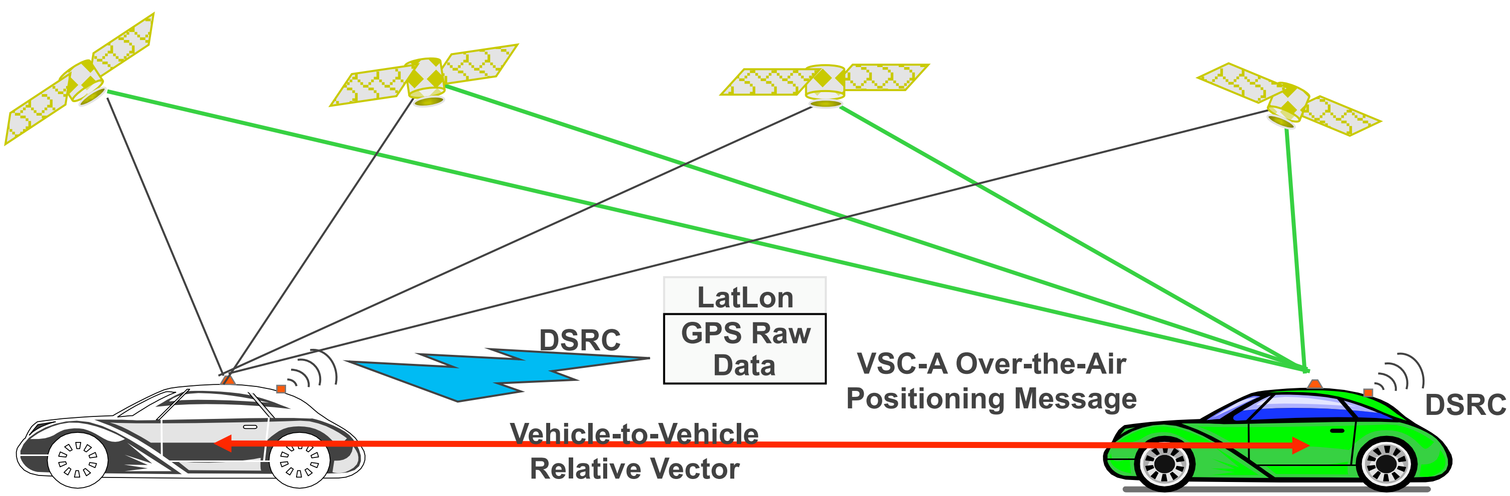
V2V communication based safety applications

- Information is transmitted between vehicles
- Enables vehicles to know where the vehicles in its vicinity are and what they are doing
- Applications include
  - Forward Collision Warning
  - Emergency Electronic Brake Light
  - Blind Spot/Lane Change Warning
  - Intersection Movement Assist
  - Do Not Pass Warning
  - Control Loss Warning



Vehicle-to-Vehicle relative positioning methods

- Primary focus is to establish the relative position vector (i.e., distance and orientation)
- VSC-A Positioning System is capable of using two relative positioning methods:
  - Using LatLon reported by two vehicles
  - Using GPS raw data and Real-Time Kinematic (RTK) positioning (RTKNav Software)



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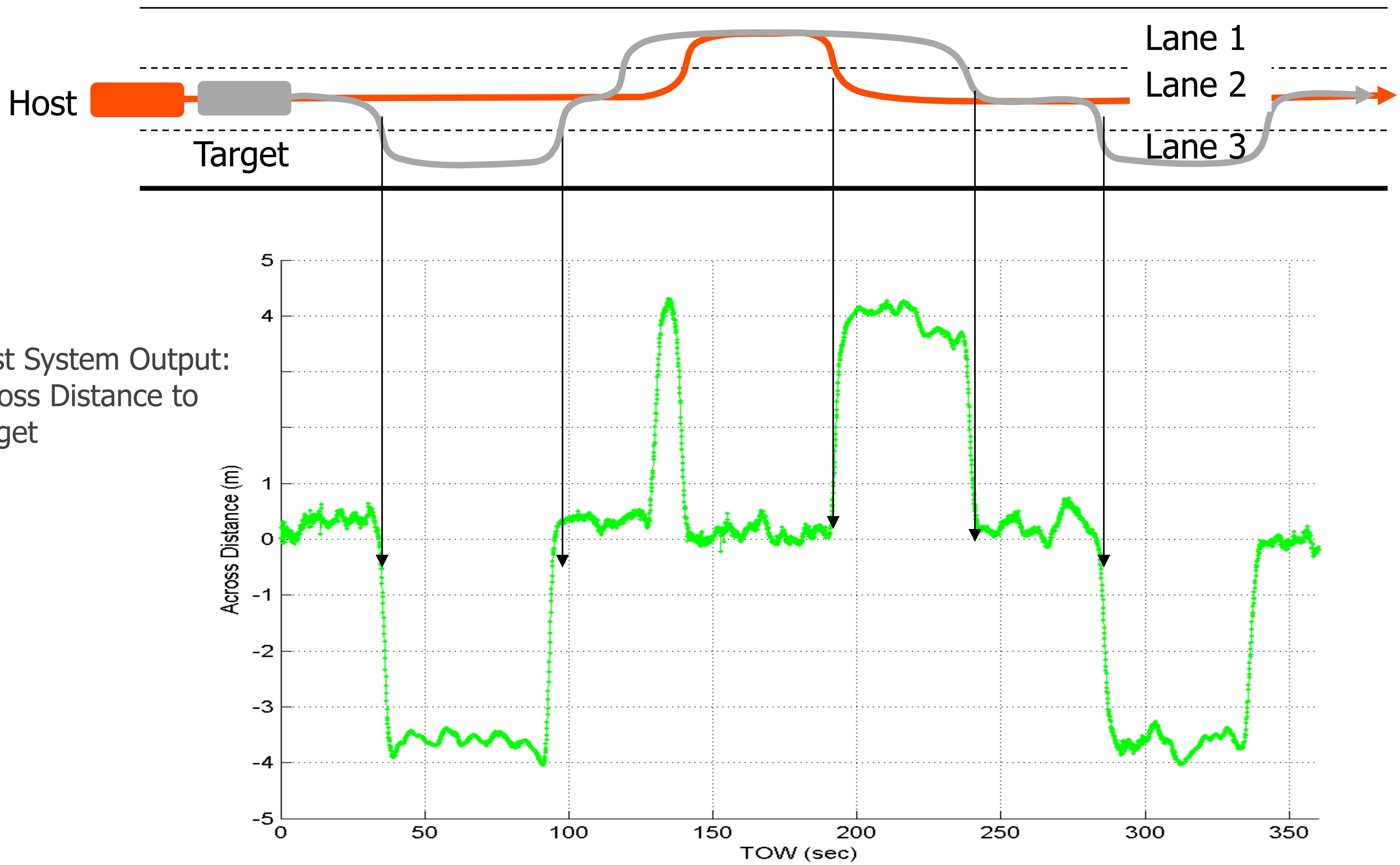
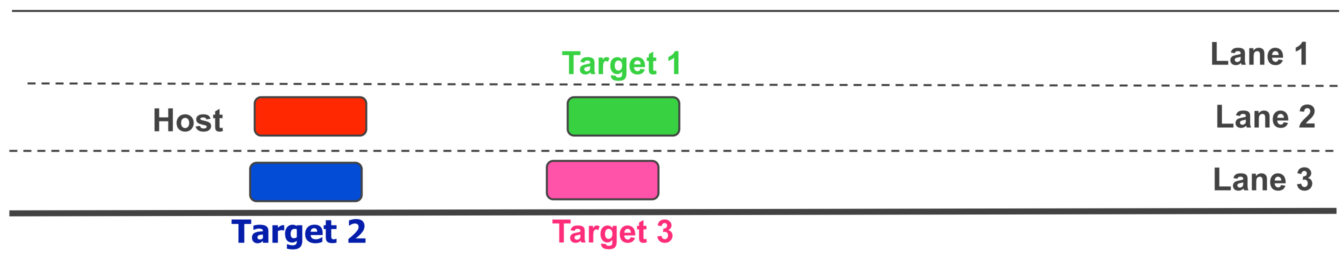
VSC-A RTK Performance

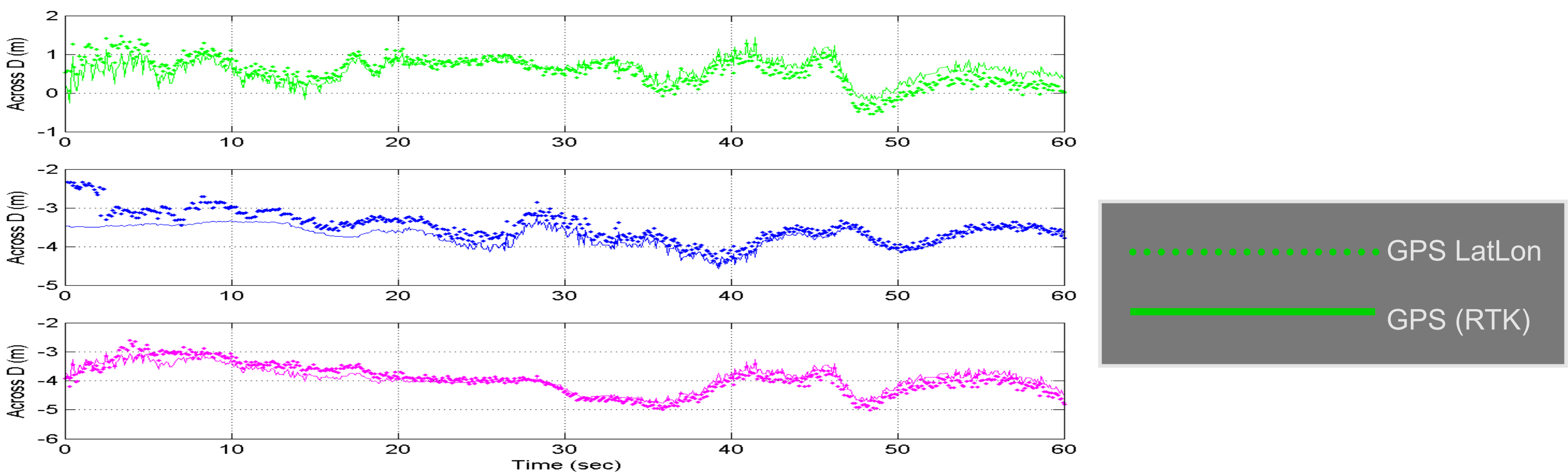
Host System Output: Across Distance to Target



VSC-A Relative positioning performance

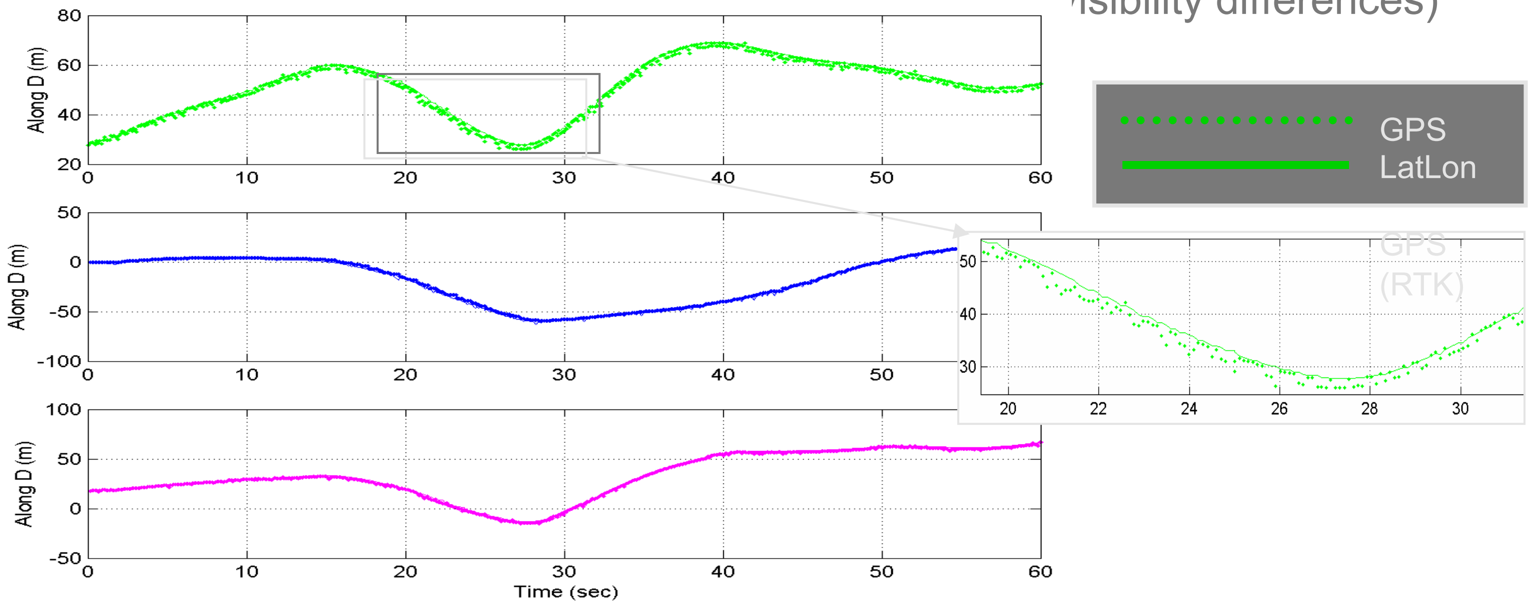


Across Distance to Each Target



Relative positioning performance

- RTK method improves the relative positioning quality by:
  - Reducing the noise (LatLon methods introduces meter-level noise)
  - Better solution continuity after RTK convergence
  - GPS blunder detection (presence of multipath and other errors) is more reliable
  - Relative accuracy improved (especially when sky visibility differences)



Conclusion

- Lane level accurate positioning can be achieved for V2V and V2I based safety applications
  - For V2I safety applications, the accuracy is around 0.5 m absolute
  - For V2V safety applications, the accuracy is around 0.5 m relative
- The accuracy depends on the availability of GPS positioning and V2X communications
- Dead-Reckoning is sufficient to bridge a gap of a few seconds for WhichLane accuracy and longer (up to several minutes, depending on the quality of the sensors) for WhichRoad accuracy

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