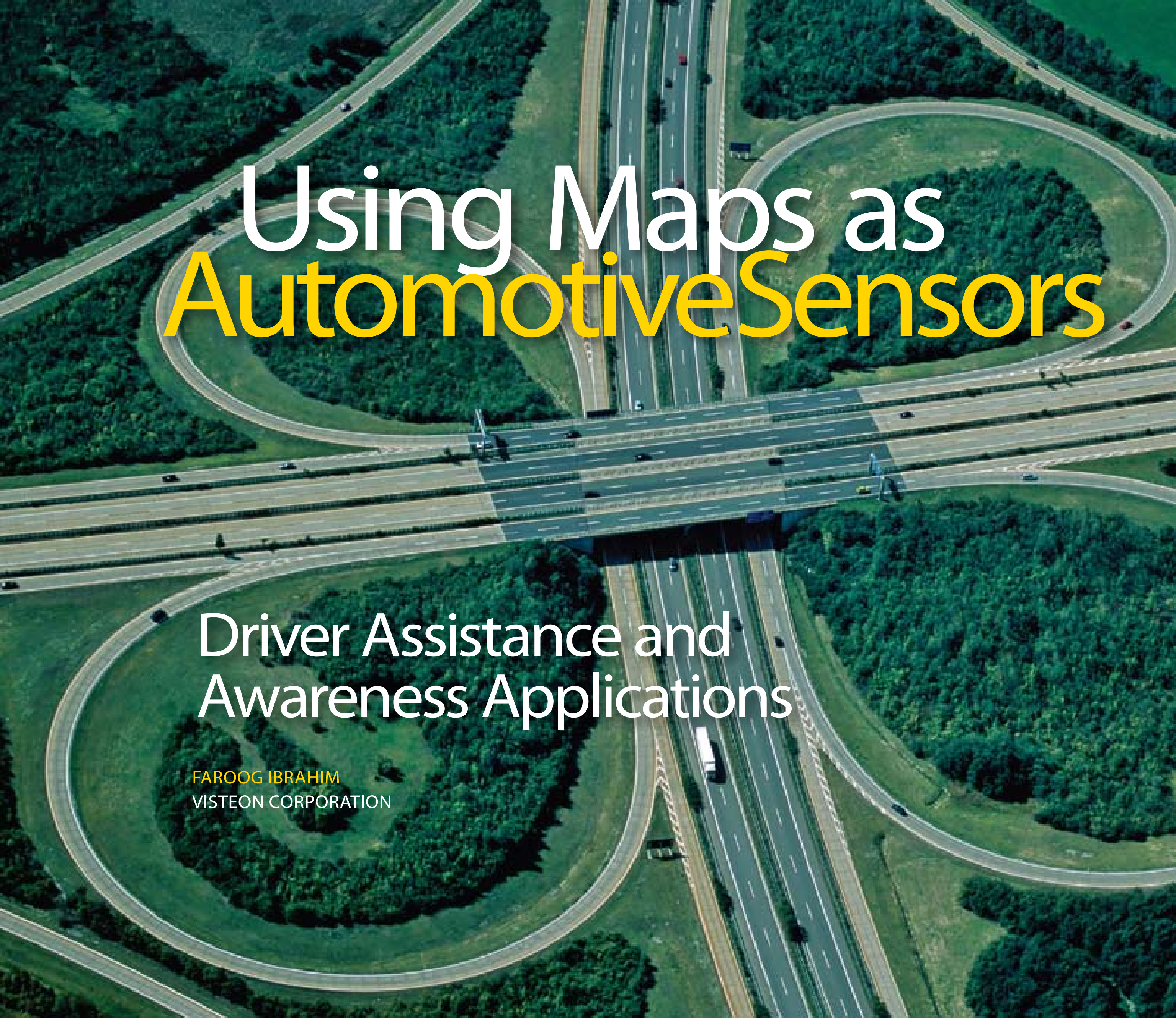

Using Maps as Automotive Sensors

Driver Assistance and Awareness Applications

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GNSS is all about positioning, sure. But for most automotive applications we need a map to help make sense of the GNSS data. A mapbase, however, can be more than a static background for location. Applied dynamically, map data can act as a sensor, providing context and situation awareness to in-vehicle systems and drivers.

Accurate real-time positioning is a necessary condition for many land transportation applications. But positioning alone cannot ensure successful and safer navigation, let alone higher-order driver assistance and awareness applications. The most common accessory to positioning is a map database — of more or less sophisticated design with greater or lesser data content and granularity.

Another resource and tool for navigation, route guidance, and advanced assistive systems is the application of geometrical principles to the positioning and mapbase data to anticipate or project upcoming conditions and events along a route.

This article introduces the map database as a sensor in driver assistance and awareness applications, which begin with a map-matched position and then look ahead from that position to determine the most likely driving path (MLP). From this calculation, we can support assistance and awareness applications such as curve speed warning, predictive adaptive front lighting systems, adaptive cruise control, and forward collision warning.

We will explore the role of MLP in these applications as well as its use in modifying route guidance instructions and map-matched positions. Finally, this article will also take up the question of map requirements and the navigation

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system interface needed for such applications.

Path Prediction

Adaptive cruise control (ACC) and forward collision warning (FCW) require systems that can determine the primary target in the host vehicle lane and then accurately estimate the geometry of the road between the host and the target vehicle. Curve speed warning (CSW) also requires knowing the geometry of the intended driving path to warn the driver of going too fast for the upcoming curve. Predictive adaptive front lighting can use the predicted road geometry to swivel the headlamps in the road curvature direction.

We primarily determine MLP by fusing vehicle signal data, lane marking information, and map database attributes. Route guidance can use the MLP data to warn the driver of potential mistakes in following a calculated route. When confidence in the accuracy of map-matched positioning is low due to geometry ambiguity (for example, at a road branching), MLP can improve the map matching performance by providing guidance in such areas. Actual road results show an impressive benefit and performance from this approach.

The most likely path determination is achieved by designing a look-head module (LAM) that scans the upcoming routes from the perspective of the vehicle position to a "look-ahead distance." The LAM determines the most probable path of the vehicle using information from vehicle positioning, lane information, lateral velocity, and vehicle signals and state.

We can predict a vehicle's most probable path and other possible alternate paths using the vehicle's travel direction, the direction of the road and if it is a one-way or two-way road, the vehicle lane data, and directional change. This information is evaluated using a cost function to weight each parameter with respect to the influence that it will have on predictions of the vehicle's most probable path.

The LAM also uses the look-ahead distance to assemble a candidate path subset that is projected out to a selected distance from the vehicle's current position. If only one possible candidate path exists, it will be returned with 100 percent confidence. Otherwise, a list of all possible candidate paths (and their associated confidence levels) within the look-ahead distance will be calculated. The most probable path, that is, the candidate path with the highest confidence level, is passed to the application (for example, a CSW algorithm).

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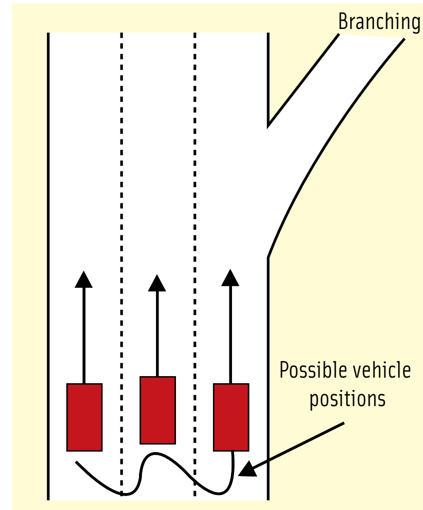


FIGURE 1 Road Branching Scenario.

An in-vehicle system can calculate the MLP by incorporating map database information such as the shape point coordinates and the advisory or the speed limit map attributes, the lane boundary types from a vision system if available, and the yaw rate, vehicle speed, throttle, brake, and turn signals from vehicle sensors.

In the scenario shown in Figure 1, if the driver initiates a right turn signal before a branching in the road, then this indicates that the driver intends to take the right branch or to perform a lane change. If the boundary type of the driving lane indicates that the driving is not in the middle lane or in the left lane, then it is more probable that the driver will take the upcoming right branch. The probability of taking the branch is a function of the vehicle location in relation to the branching point.

Driver Assistance, Awareness

Visteon has used GPS and map databases as sensors. In a road departure crash warning (RDCW) field operational test funded by the U.S. Department of Transportation (DoT) and completed last year, Visteon developed a CSW functionality

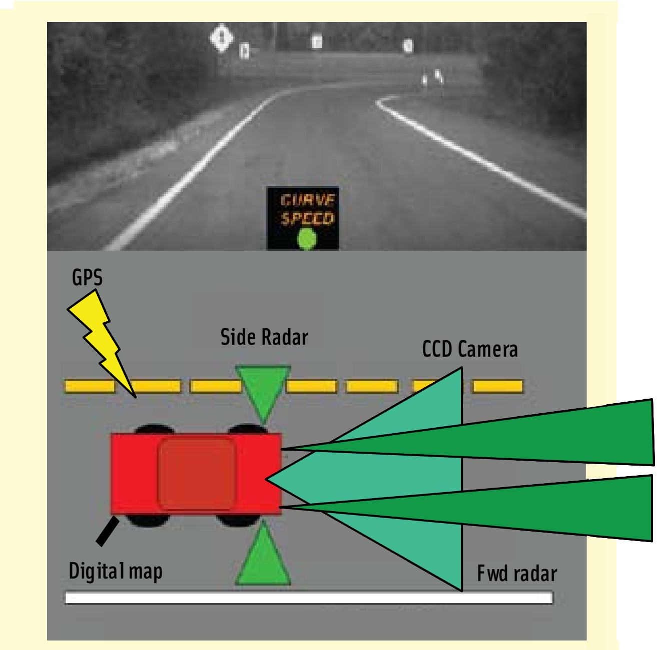


FIGURE 2 Road Departure Crash Warning Sensor Suite

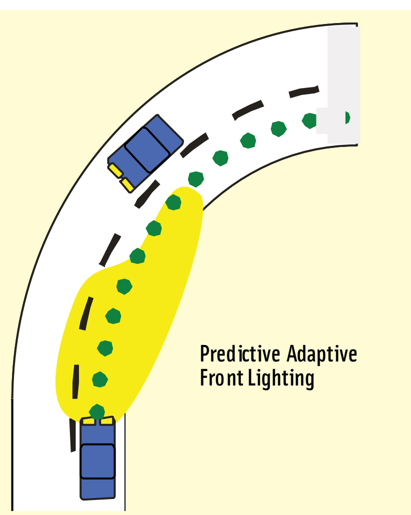


FIGURE 3 Setup for Power

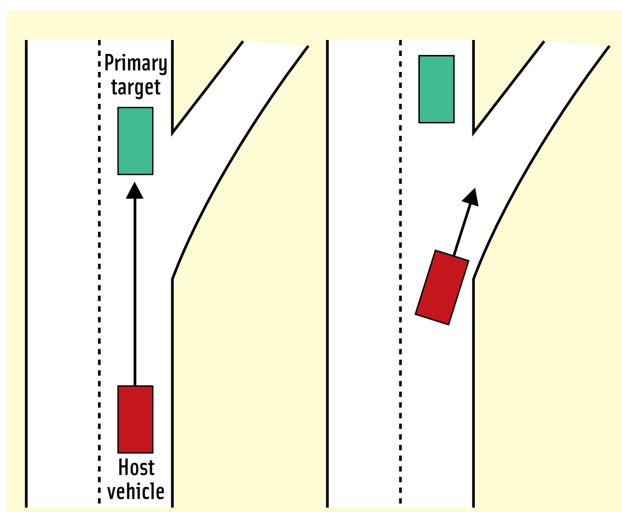


FIGURE4UsingtherampmapdatabaseattributefortheACCsystem.

using a commercial navigation system and map database. The CSW system warns the driver when the vehicle is traveling too fast for an upcoming curve by processing the map database geometric and attribute information. Figure 2 shows the RDCW sensor set.

CSW uses the navigation system to place the vehicle position on the map, and then the CSW algorithm looks ahead on the map, extracts all possible driving path candidates, determines the intended driving path, performs a curvature calculation on the geometric data of this path, and finally performs a threat assessment based on the vehicle speed and road curvature ahead.

In other applications, Visteon's predictive adaptive front-lighting systems (PAFS) uses the MLP calculation and processing to swivel the headlamps based on the upcoming MLP calculated curvature (see Figure 3). Similarly, a stop sign warning (SSW) system can use the map database information to alert the driver to an approaching halt. The stop sign information resides as an attribute in the current commercial map database.

ACC and FCW systems can use the MLP calculation to determine the in-lane primary target. The functionality of ACC and FCW depends solely on accurately estimating the geometry of the road between the host and the target vehicle in order to determine the primary target in the host vehicle lane. The host vehicle controls its speed based on the range and range rate measurements of this target.

If this target moves out of the host vehicle path, the ACC system resumes the regular speed (cruise control). However, an undesired "resume" function could occur in an exit ramp scenario (Figure 4) in which the host vehicle starts to accelerate to the set speed toward a low-speed ramp. Such undesired ACC performance could be prevented by providing the system with ramp information in the map database attributes.

Figure 5 illustrates the architecture of map database processing for driver assistance and awareness (DAA) applications. This architecture contains three main pieces: first, a commercial navigation system module that provides the vehicle position on the map; second, the path prediction module that selects the MLP and performs curvature calculation; and, third, the application module which uses the MLP information and other inputs to perform its functionality.

Land Vehicle Navigation

Route guidance is an essential feature in current land navigation systems. In this navigation feature, a driver feeds the navigation system with the desired trip destination. The route guidance algorithm calculates the route for the driver to follow. The driver may make mistakes in following the intended (calculated) route, and the route guidance system will have to adjust its instruction to correct this mistake.

Such errors mean that the driver will have to spend extra time and the vehicle will consume more gas to perform this correction. Moreover, this instruction may confuse the driver and create a hazardous situation. We can forestall such occurrences by adding a predictability feature to the route guidance algorithm by calculating the instantaneous MLP (IMLP) using the MLP algorithm. If the IMLP does not match the pre-calculated route, the route guidance system may advise the driver of a potential mistake.

Map matching can also use the MLP information in an ambiguous road geometry scenario where the combined GPS/map accuracy is not adequate to place the vehicle on the right road with a high confidence. The MLP information provides the map-matching algorithm with the expected position after the branching. This information can either strengthen the history weight (MLP matches the expectation that the vehicle will continue on the same road) — or decrease the history weight (MLP indicates that the driver will take the branch).

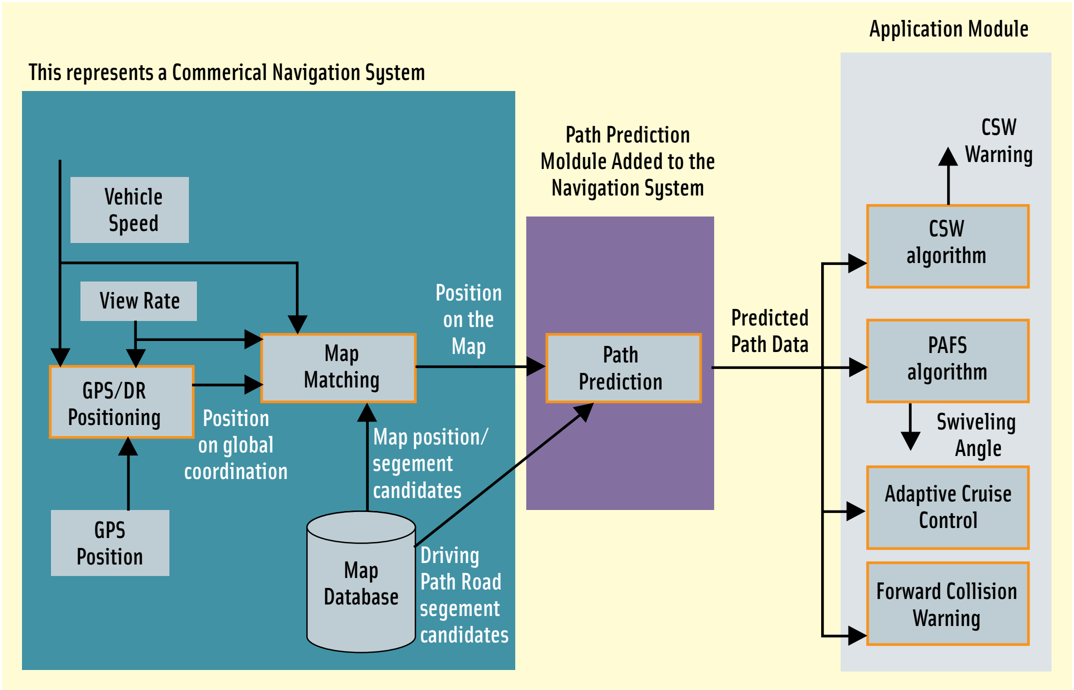


FIGURE 5 DAA Applications Using the Map database data.

The service drive/highway road scenario shown in Figure 6 is a tough one for map matching due to lack of map-matching excitation in the absence of a heading change. Both roads are parallel and close to each other. The heading angle/yaw rate information is inadequate to help us, and the combined GPS/map accuracy is not adequate to put the vehicle on the right road with a high confidence. A combination of the vehicle speed and the posted/advisory speed map database attribute can help in resolving such ambiguity, because a substantial differential in speed limits and vehicle velocities typically apply in such situations.

Map Database as a Sensor

Current commercial map databases are designed for navigation purposes. The accuracy of these maps is sufficient for navigation in a large variety of road scenarios. However, they sometime fail in such situations as service drive/highway, highway/exit ramp, fork, complex overpasses, and mountain area/single road. All of these scenarios could lead to placing the vehicle on the wrong road or off the road.

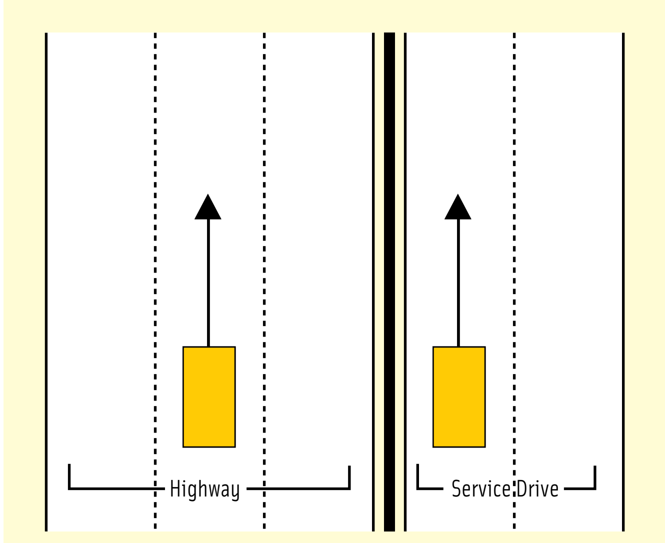


FIGURE 6 Highway/Service Drive Scenario.

Absolute and relative accuracies have been improved by the continuing replacement of the older map database shape points with higher quality advanced driver assistance system (ADAS) shape points. However, the accuracy of the ADAS map is still inadequate in many of the branching scenarios and scenarios in which three-dimensional information is required.

For path prediction algorithms, a map accuracy level that places a vehicle on the wrong road segment leads to an incorrect set of the road candidates, which produces the wrong MLP. In cases where the correct vehicle position is available, relative accuracy is the determining factor in path prediction. An accurate relative placement of the shape points along the MLP means an accurate curvature distribution along this path.

The rules and methods of creating the map database (ADAS or older) can lead to very low relative accuracy in some road scenarios. An example of that is the “connectivity rule,” which requires addi-

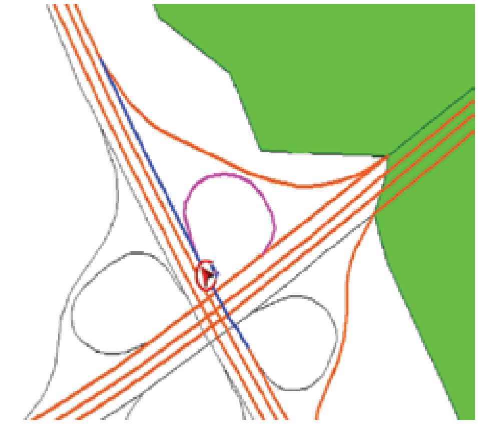


FIGURE 7 Example of Path Set Data.

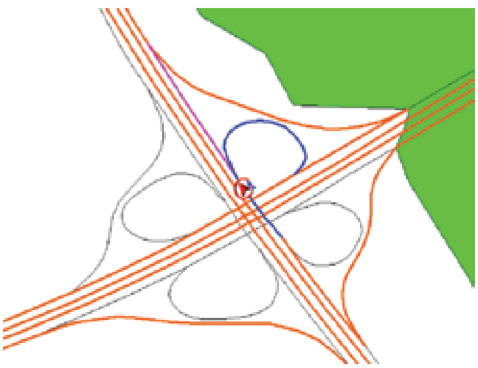


FIGURE 8 Example of Curve Speed Warning.

tion of extra shape points just for connectivity purpose, for example, to provide continuity between road segments of different roads. These added shape points are not part of the road geometry and can lead to incorrect curvature values along the path. Other rules, such as the "merging rule" in connecting a divided road with an undivided road or vice a versa or connecting an on-ramp with a main road, can also lead to a misleading representation of the path geometry.

Thinking of the map as a sensor requires, as with any other sensor, having its error sources defined and modeled. We also need to have some kind of corrective/updating capability to compensate for the changing nature of the roads and associated driving restrictions.. Furthermore, additional types of information, such as height and super elevation data, are required to extend the usage of the map for other automotive applications.

The sensing capability of a map provides detailed information about the instant road segment and the upcoming road segments.

Navigation System Interface

The sensing capability of a map provides detailed information about the instant road segment and the upcoming road segments. Figure 7 shows an example of this in which a vehicle (red arrow inside the circle) is approaching an exit ramp branching. The blue road is Path 1, which consists of two segments: the segment that the vehicle is currently on (segment before branching), and the straight (highway) segment after branching. The blue road segment followed by a magenta segment is Path 2, which also consists of two segments: the segment that the vehicle is currently on (segment before branching), and the curved (ramp) segment after branching.

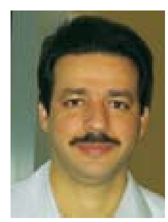
The path set in Figure 7 exemplifies how the navigation unit may output the map sensor data. The path data could be described by a number of curvature points along a look-ahead travel distance of the corresponding path. Each curvature point can be described by global latitude and longitude coordinates, vehicle centered true north/east coordinates, curvature value, confidence value, number of lanes, and travel distance from the vehicle location.

Figure 8 shows an application-specific path data. In this scenario the path prediction algorithm senses that the driver is probably taking the exit ramp to the right. The curvature data and other data of the MLP are sent to the CSW threat assessment algorithm, which may initiate a CSW warning at some distance before branching.

Conclusion

Map database can provide detailed information of the road segment at the vehicle position and the road segments ahead of the vehicle. This information when processed can be used for advanced driver assistance and awareness applications Moreover, these systems should incorporate a map corrective/updating capability due to the changing nature of the roads and associated driving restrictions. Map database errors can arise in such road scenarios as merging, road connections (overpasses), divided/undivided roads, and mountains areas In order to optimally use the map database, such error sources should be defined and modeled. Furthermore, inclusion of additional information such as height or elevation could extend the usage of the map for other automotive applications. From a commercialization perspective, it is recommended to standardize the navigation system interface.

Author



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Additional Resources

NHTSA, "Status Report on USDOT Project "An Intelligent Vehicle Initiative Road Departure Crash Warning Field Operational Test," www-nrd.nhtsa.dot.gov, 2005.

T. Pilutti, F. Ibrahim, M. Palmer, and A. Waldis, "Vehicle Position Analysis of a Commercial Navigation System," SRR-1999-0169, November 17, 1999.