The Potential of Precision Maps in Intelligent Vehicles

Christopher K. H. Wilson, Seth Rogers, Shawn Weisenburger

Abstract-- With the general availability of differential GPS and low cost inertial sensors it will soon be practical to routinely locate a vehicle to within a lane on a road. For additional cost, positions of decimeter accuracy will be available. Uncoordinated probe vehicles with positioning capabilities and communications can be used to map the lane network with decimeter accuracy. This mapping technique provides data with high reliability that is suitable for safety applications. The data collected can be used to develop a record of any sensible parameter on the vehicle. Thus, this technique may be used to provide calibration data to other sensor systems based on vehicle position. This paper describes some of the collection techniques and the characteristics of the collected data, as well as some of the applications that may be enabled by this data. The paper finishes by identifying problems that must be addressed to bring this technology to fruition.

Index Terms-- mapping, vehicle positioning

I. Introduction

We believe that new information technologies enable applications that will significantly improve vehicle safety. Specific technologies are global positioning, computer processing and communications. Our fundamental assumption is the availability of a large number of position-aware probe vehicles. Most of these probes are personal vehicles not under any sort of central direction as to their movements. Each vehicle reports its position, as well as other information, to a central server. This server can correlate information from many vehicles, infer characteristics of the vehicle operating space, and provide that information back to the probes and other position-aware vehicles. This information is essentially a history of previous vehicles' experiences at a given location which can be used to optimize the performance and safety of position-aware vehicles as they approach a location.

This paper will examine applications that are enabled by such a scenario, and also identify several problems that we face in pursuing these applications with the above technology.

II. Positioning Technology

Satellite based positioning systems, such as the US Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS) can provide an absolute position anywhere on the earth where at least four of the satellites can be clearly observed. Using commonly available differential techniques, accuracy of 1 meter or better is often obtained.

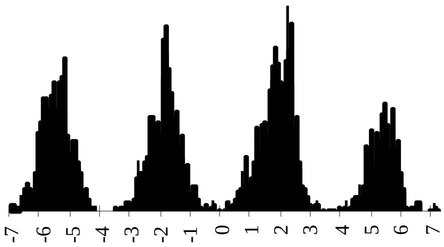

Fig. 1. Distribution of GPS based vehicle positions across roadway.

Figure 1 shows the distribution of vehicles across a four lane freeway based on differential GPS positions alone. This data is from 22 passes by vehicles driving normally along a curved section of road approximately 2 km long. All data that was internally identifiable as bad, mainly due to losses of the differential correction signal, was eliminated. This data, collected under good conditions shows a distribution with a 50-55cm standard deviation about the lane centerlines after 4-6 passes per lane. Some of this error is due to driving variability, most is due to GPS.

Satellite positioning technology must be supplemented with other dead reckoning sensors in order to provide an accurate location at all times. Readily available data include the wheel speed and turn rate from a moderate quality gyroscope. Wheel speed is available on all cars, and many high end vehicles have a gyroscope for stability control systems, although the quality of this gyroscope is not sufficient for navigation. The integrated GPS/dead reckoning system provides a much more robust vehicle position. The vehicle shown in Figure 2 has an integrated DGPS, gyroscope, and wheel speed positioning system developed at Daimler Benz RTNA. Driving tests show instantaneous position accuracies of around 30cm in good conditions. This accuracy degrades significantly in areas with many overhead obstructions, or with bad differential signal coverage. However, the position accuracy is usually known and applications can adjust functionality accordingly.

All of the authors are with the Daimler-Benz Research and Technology Center, 1510 Page Mill Rd. Palo Alto, CA. 94304. *Lastname@rtna.daimlerbenz.com*

Fig. 2. Vehicle with inertial and dead reckoning positioning systems.

The primary limitation of this system is multipath induced error, which can affect the system at unknown times in currently undetectable ways. We mention this again later as a problem that requires significantly more research. The above system is currently too expensive for commercial deployment, but we believe that will change over the next few years.

III. Map Refinement

A telematics system can relay vehicle position information back to a central server. The collected data from many vehicles and many trips can be combined to form accurate lane centers. The resulting map has the following characteristics:

High integrity

1. Accuracy is known on a point by point basis
2. Map is insensitive to errors from inputs
3. Little human interaction required
4. Inherent feedback loop

High accuracy

1. Map shows actual driving behavior
2. Accuracy increases with time to approximately 10cm

Timely

1. Feedback loop may have a time constant of weeks to seconds

The data shown in Figure 1 was processed to derive the number of lanes and lane centerline positions. We postulate the existence of an ideal centerline for each lane which all drivers are trying to follow. Using the distribution of our mapped centerlines after each successive pass, we calculate the accuracy with which we know the ideal centerline. The data in Figure 3 shows that after 22 passes down a lane, our calculated centerline is within 15 centimeters of the ideal centerline. This accuracy is within driver lanekeeping ability, and is accurate enough for many applications short of autonomous control.

In our experiments so far we collect position data and refine the road geometry information. Position data is readily available, and must form the basis for the map. It is also possible to collect and refine any data that is electronically available in the vehicle. Thus, to determine the location of a long tunnel we could monitor headlight status, or to identify the road surface or quality

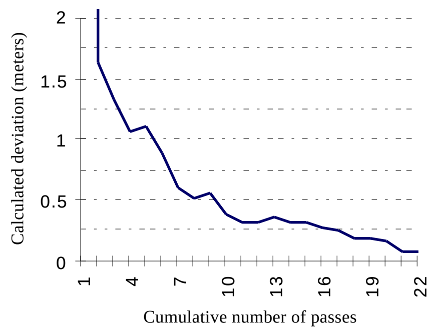

Fig. 3. Reduction in the calculated deviation of the map from the ideal centerline as the number of vehicle passes increases.

at a given location, monitor the suspension. Once again correlating data from many vehicles should allow us to infer characteristics quite accurately.

IV. Applications

Several classes of applications are enabled when maps with safety level integrity are available. Figure 4 shows some of these applications.

A. Basic Applications

This describes the applications that are enabled by the maps and positioning capabilities alone as described above.

The most accessible of the basic applications is the curve

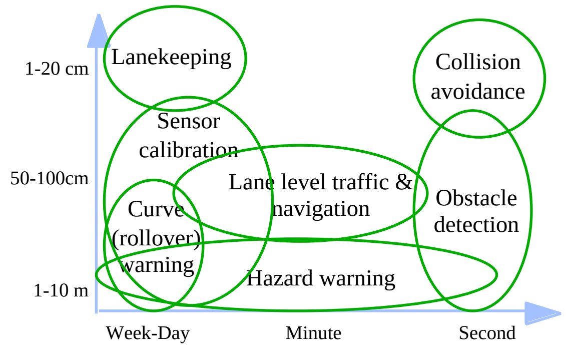

Fig. 4. Example applications as a function of position accuracy and communications latency

warning, or rollover warning application. This application warns the driver that the vehicle is moving too fast to negotiate the turn ahead. This may be possible with existing maps and positioning systems, however more precise systems will allow the developer to further optimize the warnings and minimize false alarms.

Hazard warning is technically possible now with existing navigation systems, but requires enhancements to the map database. For this application the hazards must be known in advance and be incorporated into the map. Such hazards would include planned lane construction, or historically hazardous locations. With the enhanced capabilities proposed above these warnings could be provided at the lane level and in a more timely manner.

Traffic control warning provides a driver with notification of the presence of a traffic control, such as a stop sign. This application requires fairly precise location and position in order to time the warning correctly. This also requires a map containing the location of the traffic control of interest. Since the location of traffic controls changes fairly rapidly, an automated system, as described above, is an attractive method for obtaining this information. In a limited test we have demonstrated the capability to infer the presence of stop signs and traffic lights at intersections with 100% accuracy [1]. This result is based solely on position and time data obtained from probe vehicles. This inference technique works well with position accuracies on the order of ten meters, although greater accuracy is probably required to time warnings.

Lanekeeping may be enabled with the basic maps and positioning system postulated above. The maps are certainly accurate enough, however the instantaneous position is at best on the order of 30 cm, and can easily degrade to a meter or worse. Thus, under good conditions, such as open highways, lanekeeping is feasible. With less than optimal conditions, say one meter accuracy, lanekeeping capability is marginal. The value of a lanekeeping system under these conditions is unknown and can not be predicted without driver behavior baseline data.

In addition to safety applications there are also many convenience applications that are enabled by this basic technology such as improved transmission control, traffic monitoring, and navigation.

B. Precision positioning applications

Differential GPS techniques exist to resolve the location of a moving vehicle to within a few centimeters [2]. These techniques are currently being tested for aircraft landings in low visibility conditions, and are being used by agricultural and mining vehicles for precision applications. The ground vehicle operating on public roads is a much more difficult problem, yet progress is underway [3]. We project that proposed upgrades to GPS satellites, as well as other infrastructure, will make precision positioning practical for very high end vehicles around 2005, and probably practical for most vehicles sometime late in the decade. The quality of the position without GPS will degrade below 1 meter fairly quickly, thus the main issue for these applications is likely to be graceful degradation to meter level accuracy applications.

Given a precise position and 20cm accuracy maps lanekeeping becomes a fairly straightforward proposition. The ability to refine and validate the maps also increases significantly.

With this precision it will be possible to warn of individual potholes on a road. Some control applications will also become feasible.

C. Sensor fusion applications

Sensor fusion applications are perhaps some of the most interesting to contemplate. The idea here is that an off-board sensor system, such as a radar or vision system, can be calibrated for a specific location. This will help to reduce false alarms, and increase the reliability of all systems. We strongly suspect that as automotive radars are deployed, certain locations will be found to cause problems, such as a rotating sign by the side of the road or a highly reflective road surface. If these can be automatically detected, either by the system itself, or by correlating driver response with the warnings, then that information can be transmitted and correlated across time and various probe vehicles. This may also serve as a signal to send a human out and check the spot. If appropriate, the calibration parameters of the radar can be adjusted in the future as it approaches the location of the problem. We suspect that the problems with a vision system will be even more severe, depending on striping in the road, lighting, and adjacent structures. Certainly calibrating the sensor to look for dark lines, light lines, to not look for lines, or ignore certain information will improve performance.

As more sensor systems are deployed on a given vehicle, the map can prioritize the signals from the various sensors based on historic performance at that location.
The sensor fusion also works to aid in the development and refinement of maps. In areas where the location system does not work, such as long tunnels, a vision system could be used for mapping. The vision system or radar might also identify cross streets as the vehicle approaches.

D. Low communication latency applications

We have postulated a scheme whereby the vehicle collects data which is then communicated to a central server where the data is correlated and refined. The resulting information is then sent back to the vehicle. The latency of this loop determines age of the information. It is possible today for this latency to be on the order of seconds with an open cellular connection. This will certainly become generally practical in the future as more and more communication paths are enabled. For the low latency applications below, high penetration is also assumed since a leading vehicle in front is required to sense dynamic situations.

With a latency of seconds obstacle avoidance is probably the most valuable application. An obstacle in this case is anything that the vehicle in front can sense, or which the correlated behavior of the preceding vehicles indicates. Thus a mattress in the road might be directly detected by a vision system of a preceding vehicle, or inferred from all vehicles in a given lane moving out of that lane, or potentially even by a sharp swerve of a probe vehicle ahead.

E. Combined Applications

Ultimately, with time constants of fractions of a second, (possibly through direct car to car communication), positions on the order of centimeters, and fusion with other sensors for verification, this technology will enable collision avoidance. The combination of absolute position from the systems described here, and relative location from other off board systems, will likely provide the redundancy required for a practical system.

V. Problems

A. Map Representation

None of the digital map formats available today are capable of storing the road network with adequate efficiency at the accuracies specified. Part of the problem is that we do not even have a clear understanding of the information that must be in a map to support the above applications.

Required map characteristics are as follows:

1. high precision
2. support different levels of accuracy
3. accuracy can be increased in local areas independently of others
4. identifies all lanes and turning options
5. can contain information for other sensor systems

One possible representation that has appeal for the above is a hexagonal grid, each cell of which contains the percentage of cars on the road segment that pass through that cell, and the percentage of those cars that leave by each of the 6 faces (Figure 5). This representation has the advantage that it immediately indicates if a given vehicle is behaving abnormally.

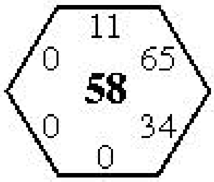

Fig. 5. Cell of a map representation suitable for lane departure warning. The central element is the probability of a car on the segment passing through the cell. The peripheral numbers are the probability that a car leaves by the nearby face of the hexagon.

B. Multipath

Multipath on a signal occurs when the receiver antenna picks up signals that have been reflected off of a surface between the emitter and receiver. GPS multipath can shift the computed position of the receiver significantly. For vehicles the primary source of multipath is buildings, overhead foliage, and other vehicles. Multipath is often detected due to differences between GPS location and that computed using other sensors, however, the GPS receiver itself is often unaware of the multipath condition, thus the GPS positions are given undue weight in the position solution, resulting in erroneous track for the vehicle.

We have observed cases when a truck in an adjacent lane has shifted the GPS position by several meters, with no internal indication that there is a problem.
Multipath is a very significant topic within the GPS industry with hundreds of people looking for solutions to this problem. We expect that a solution based on better receiver technology, multiple receivers, and mapping of high multipath areas will mitigate this problem.

C. Statistical Validity

In order to implement these applications we must have a much better understanding of driver behavior under normal conditions. Where are typical drivers in a given lane? Does this depend on the road geometry, terrain, or the presence of other vehicles? This will allow us to determine acceptable parameters for a lane departure system.

In addition we must have a much more complete understanding of the statistical accuracy of the vehicle location system, and of the map database. The statistical properties of the map database and its refinement and updating processes are especially interesting since they are inherently dynamic. The ability to rapidly detect changes in the database is crucial to the various avoidance applications.

VI. Conclusion

We believe that positioning, mapping and communication technologies can be combined to enable novel position aware safety applications. Position aware safety systems will work well to complement and mutually enhance the performance of many of the sensors and systems proposed for intelligent vehicles.

VII. References

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