Deployment of Digital Vehicle/Highway Technology for Safety Enhancement

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Abstract

Although currently seatbelts and airbags are world widely used, there are still more than 40,000 people killed annually in traffic accidents. Referred to David Breed's "Road to Zero Fatalities" (RtZF®) concept, this paper mainly discusses how to develop and deploy a safety warning system using high precision digital road maps and a combination of various vehicle status sensory techniques, without or with a minimum requirement of additional road infrastructures. This system will help to avoid accidents and enhance safety by warning drivers of possible hazardous situations in advance.

1 Introduction

Despite the gains that have been made in traffic safety programs in the U.S. over the last several decades through a crackdown on drunk driving, increased seatbelt usage, and the more widespread use of airbags, traffic crashes are still the leading cause of death for Americans between the ages of 4 and 33. It was reported in ABC News that in 2001, 42,116 Americans were killed in traffic collisions, up slightly from the 41,945 killed in 2000. And according to Government forecasts, this number will gradually increase with increasing vehicle usage and slow highway construction. To combat fatalities, David Breed and his ITI Inc. has proposed the concept of "Road to Zero Fatalities" (RtZF®) that has shifted the vehicle/highway paradigm from "projects" to "process". The basic idea of RtZF is to prevent the traffic accidents based on the exact vehicle location obtained through a combination of differential global positioning system (DGPS), inertial guidance, and strategically placed infrastructure, which periodically allows the vehicle to know its exact location. However, it will take many years of developing and testing before the complete RtZF® or similar system can be implemented.

In the following sections we will discuss how to develop, test and deploy a safety warning system using high precision digital road maps and a combination of various vehicle status sensory techniques, without or with a minimum requirement of additional road infrastructures. The basic technical concept is that if a vehicle knows within centimeters where it is and where the roadway is to a similar precision, many highway accidents can be avoided by warning drivers of possible hazardous situations using the state of the art vehicle sensory and geo-location technology. Furthermore, if the vehicle also knows where all other vehicles in its vicinity are through vehicle-to-vehicle communication, most highway fatalities can be eliminated. However, this paper will focus on the warning aspect only.

2 System Architecture

This new safety warning system will provide the following two main functions: 1) Warning the driver passively when a vehicle is crossing the road sideline (i.e., creating electronic rumbling strips) or the lane without turning signals (i.e., creating electronic lanes); and 2) Warning the driver proactively the possible hazardous situation based the current vehicle position, orientation, speed and the current road condition. The second warning function will need a sophisticated decision-making system to identify the hazardous driving situation based vehicle status and road condition. For example, via spatial decision tree-application [1], we can build up decision making agents through analysis of geographical database on the road accidents [8], on the road networks, on the vehicle flows, or sometimes on the mobility of inhabitants and predict the accident risk of current vehicles in real time.

The system architecture is demonstrated in figure 1.This safety warning system utilizes the typical down-to-top hierarchy architecture. The whole system is comprised of three layers: sensor system layer, embedded core layer and safety warning interface layer.

1. Sensors System Layer: this layer includes several different types of sensors for collecting variable road and vehicle real time conditions. Sensors system provides the upper layer-embedded core - with real time data to help it make decision if current situation of the vehicle is safe or it is time to send the driver warning information.

2. Embedded Core Layer: this layer is the core of the safety warning system. It is responsible to analyze present road and vehicle states and combine them with GIS data [2] built in the system in advance to find the possibility of hazard. Considering the real-time requirement of the system, the embedded core is highly qualified, effective, accurate, and reliable.

3. Safety Warning Interface: with video/audio multimedia streams help, the safety warning interface based on the decision from the embedded core display accurate and vital warning information in time.

Among these layers interaction, real-time data plays the essential role. Undoubtedly, the proposed system is a hard real-time system that would fail if its timing requirements were not met [3]. So during the process of the system implementation, we emphasize time-critical requirement in the detail designs of each layer especially.

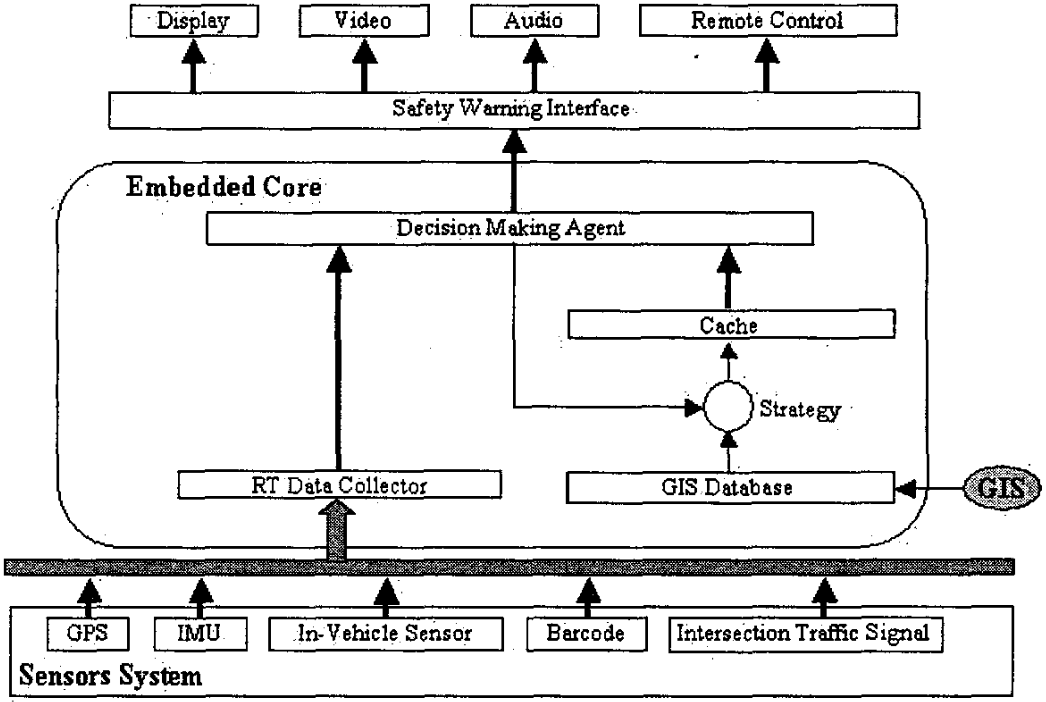

Figure 1: System Architecture (➡ : Real time data flow, → : Non-real-time data flow)

3 System Design

This section will demonstrate the design of the proposed system and detail works that are required to accomplish our goal. The safety warning system is composed of the following eight tasks:

1. Design of High Precision and Real-time Accessible GIS-Databases
2. Procedures of Data Collection and Fusion for GIS-Databases
3. Construction and Implementation of Calibration Bases
4. GIS-Database Population for I-10 Corridor from Phoenix to Tucson
5. Selection and Validation of Vehicle Status Sensors
6. Integration and Fusion of In-Vehicle Sensors and GPS/IMU Sensors
7. Development of Prototype Safety Warning Interfaces
8. Test, Implementation, and Deployment of Prototype Safety Warning Systems

Each of those tasks will be elaborated in the sequel.

A. Design of High Precision and Real-time Accessible GIS-Databases

General-purpose GIS (Geographical Information System) databases alone which are conventionally off-line [4] are not suitable for the proposed system due to the high requirements for position accuracy and real-time accessibility here. A cache-type structure, similar to the one used widely in computers for efficient real-time memory management, is utilized to establish a high precision and real-time accessible GIS-database for the project. This special GIS database consists of two parts: a small real-time executable digital map and a large off-line GIS database. The small real-time digital map is generated from the large off-line GIS database according to the current vehicle location, velocity and warning specification provided. The small digital map contains only the sufficient information that can be manipulated in real-time to warn the driver of any specified possible driving hazard with respect to its currently location and velocity on the road.

In this system, a commercial GIS-Databases (such as ArcView [5] or MapInfo [6]) is required to be selected and evaluated for constructing the large off-line GIS database, while the small real-time digital map will be developed and tested based on the selection of GIS-Databases since this digital map cache interacts with GIS-Database frequently via the interfaces provided by this GIS-Database.

B. Procedures of Data Collection and Fusion for GIS-Databases

Procedures for collecting and verifying data for the GIS database established are described as follows: First, the procedure for data collection using a single sensor will be created, and then the algorithm for data fusion with multiple sensors will be developed, and finally, the steps for verifying data integrity with multiple sensors will be established. It's also important to develop a computer simulation program to verify the proposed procedure, algorithm, and steps. It will then be carried out for a small road segment for testing, and modification, and improvement.

C. Construction and Implementation of Calibration Bases

It is essential to establish barcode type calibration bases along highway that would allow a vehicle to read and calibrate its position, orientation, and velocity in real-time with respect to a local highway coordinate system, and then transform to a global highway coordinate system. Calibration bases can also provide the preview road/lane information for specified distances. The acquired position, orientation, and velocity will be used to correct and calibrate other information provided by vehicle sensors periodically for high accuracy and reliability. They can also be used in cases of sensor failures and/or out of range such as under bridges or in tunnels.

In this task, it is also necessary to paint barcodes on the road and develop a laser-based barcode reading device for a vehicle to read those barcodes. Algorithms for fast, accurate and reliable barcode signal processes [9] are indispensable to design and test to handle the possible convolution distortion environments. The method of determining the number of calibration bases and distribution along a given segment of a highway is also investigated during the process of the establishment of calibration bases.

D. GIS-Database Population for I-10 Corridor from Phoenix to Tucson

In this task, we apply the methods and procedures established in Task 1, Task 2, and Task 3 to create a high precision and real-time accessible GIS database (it will be referred as the Digital Road Map in this paper) for a selected road segment, i.e. in Arizona. For example the segment will be the 100 miles I-10 corridor between Phoenix and Tucson.

The position accuracy and access time are the two main requirements for the Digital Road Map. Those two requirements must be realistic yet useful in implementing safety warning systems. The selected segment provides a test bed for the results established in Tasks 1, 2, and 3. Based on the result of this task, it is possible that we may have to change and/or modify Task 1, Task 2, and Task 3.

E. Selection and Validation of Vehicle Status Sensors [7]

Sensory system is the key component responsible to collect real-time data in the system. So the selection of calibration bases and sensors will directly impact the performance of the integrated system. It is essential to evaluate the use of calibration bases and four types of sensors for collecting vehicle status information such as position, orientation, and velocity. The four types of sensors are: 1) In-vehicle sensors (an encoder and a high precision semiconductor potentiometer) for measuring orientation and speed of a vehicle; 2) Video cameras for identifying the relative position of a vehicle with respect to road edges or lines (an autotracking sensor); 3) Inertia measurement units (IMUs) for finding the relative orientation and acceleration of a vehicle; and 4) GPS or DGPS receivers for obtaining the absolute position of a vehicle.

The first three type sensors provide continuous information, while GPS and calibration bases offer discrete information at a given time period and distance. The continuous and discrete information will be used individually and jointly to find the vehicle status information. The discrete information will be used to calibrate the continuous information periodically, while the continuous information to interpolate the discrete information between the two acquisition points.

We believe that at least one continuous type and one discrete type sensor must be used in this system. To evaluate different types of sensors, the system will acquire one of each sensor, evaluate their performance and then select the appropriate ones based on the accuracy, real-time accessibility, and reliability consideration. And the cost of those sensors is also a factor.

F. Integration and Fusion of In-Vehicle Sensors and GPS/IMU Sensors

It is clear that GPS receivers will be one of the sensors selected for this system. Another sensor that provides continuous information must be used to augment the GPS information. Otherwise one will not be able to find the vehicle orientation and location accurately and reliably, especially for high speed driving as well as between two GPS signal points. This will make it impossible to incorporate vehicle sizes into consideration when issuing warning to drivers. Therefore, we need to develop and test algorithms that will combine the information of GPS, in-vehicle sensors and/or IMU sensors.

The basic strategy is to use in-vehicle and/or IMU signals to interpolate the GPS information between GPS sampling points, and to calibrate in-vehicle and/or IMU signals with GPS at each sampling point. This will offer us a robust position, orientation, and speed information with high precision and reliability. A similar strategy to integrate the calibration bases with GPS, in-vehicle and/or IMU will be developed.

G. Development of Prototype Safety Warning Interfaces

Based on the Digital Road Map, vehicle status sensors, and vehicle locating algorithms developed in the previous tasks, a prototype safety warning system will be constructed. The safety warning interface will provide two main warning functions described in System Architecture section. The whole electronic hardware and software for the safety warning interfaces is combined with video and audio multimedia capacity.

H. Test, Implementation, and Deployment of Prototype Safety Warning Systems

The safety warning system developed is required to be installed on vehicles, tested and deployed on the selected road segments. This task is divided into two stages that will focus on the operational and precision aspects respectively. The first stage is focused on the operational aspect using low accuracy sensors and without the differential GPS infrastructure. In this stage, the safety warning system hardware and software with low-grade sensors is tested and evaluated, and a correct procedure for operations will be established. The second stage aims to improve the accuracy aspect to the point of providing meaningful warning information using high precision sensors with the differential GPS infrastructure. The result of this task will be utilized to validate and refine the previous tasks.

4. Conclusion

In this paper, we demonstrate the prototype and detail tasks of the safe warning system that helps to avoid accidents via warning drivers in advance. And warning signals are generated based on analysis of the exact vehicle location obtained through a combination of DGPS, vehicle sensory and geo-location technology, which periodically allows the vehicle to know its exact location. Actually, there are still many aspects of this system necessary to investigate and develop in detail, i.e. decision-making algorithms, methods for barcode signal process etc. From the discussion above, we can see that this system is definitely applicable and reliable.

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