2004 IEEE Intelligent Transportation Systems Conference
Washington, D.C., USA, October 3-6, 2004

Development of the Side Component of the Transit Integrated Collision Warning System

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***Abstract*— This paper describes the development activities leading up to field testing of the transit integrated collision warning system, with special attention to the side component. Two buses, one each in California and Pennsylvania, have been outfitted with sensors, cameras, computers, and driver-vehicle interfaces in order to detect threats and generate appropriate warnings. The overall project goals, integrated concept, side component features, and future plans are documented here.**

I. Introduction

In the fall of 2001, the Federal Transit Administration (FTA) merged two existing research efforts on transit collision warning within the Intelligent Vehicle Initiative program [1]. This brought together existing efforts to develop a side collision warning system (SCWS, Pennsylvania, [2]) and a forward collision warning system (FCWS, California [3]). This joint effort became known as the Integrated Collision Warning System (ICWS) project.

By integrating both systems the plan is to accomplish following objectives:

1) Integrate the advanced side collision warning and frontal collision warning systems into a unified whole with one transit operator interface.
2) Specify and build a usable driver vehicle interface (DVI) prototype.
3) Conduct limited operational testing and evaluation of enhanced commercial systems in actual transit use.
4) Reduce development risks and accelerate deployment of transit collision warning systems by integrating marketing, manufacturing, and commercialization considerations into the development process.

This paper is focused on the enhancements made to the side component since the prior project [2, 4, 5] and describing how this work fits into the project as a whole.

Manuscript received April 1, 2004. This work was supported in part by the U.S. Department of Transportation under Grant 250969449000 and PennDOT grants PA-26-7006-02 and PA-26-7006-03.

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A. Side Collisions in Transit Operations

Earlier analyses by the team under the project specific to side collisions formulated conclusions specific to side collision warning systems for transit buses [4]:

1) Many of the most serious accidents involve pedestrians.
2) Only a very small percentage of side collisions are classical lane change or merge accidents.
3) Many of the bus accidents involve objects approaching from the side.
4) The line between safe and unsafe situations is very tight.
5) In a quarter of all pedestrian fatalities, the pedestrian is partially or completely underneath the bus.
6) In many cases the bus driver does not notice that a collision with a pedestrian happened.
7) In most cases it is not the bus driver who created the dangerous situation.

These issues are less pronounced in the collision warning efforts underway for the other vehicle platforms. As such, new algorithms, concepts, and methods are required to address these unique concerns.

It has been estimated that side collisions incur such a high cost that a side collision warning system for buses in the $12,000 price range would be recouped in approximately 3 years, not including costs related to fraudulent claims and driver stress [5].

B. Transit Collision Warning Nuances

There are a number of transit operations characteristics that make this development effort particularly challenging. First and foremost, transit operators routinely drive close to other vehicles, obstacles, and pedestrians. The former two are specifically related to the size and handling of the vehicles in question and the locales in which they operate. The latter is due to events near bus stops where drivers are expected to pull close to the curb, thus coming into close proximity to waiting patrons and other pedestrians (and fixed objects like bus shelters).

Also worth highlighting is the environment the driver operates in and the perceptual demands that accompany

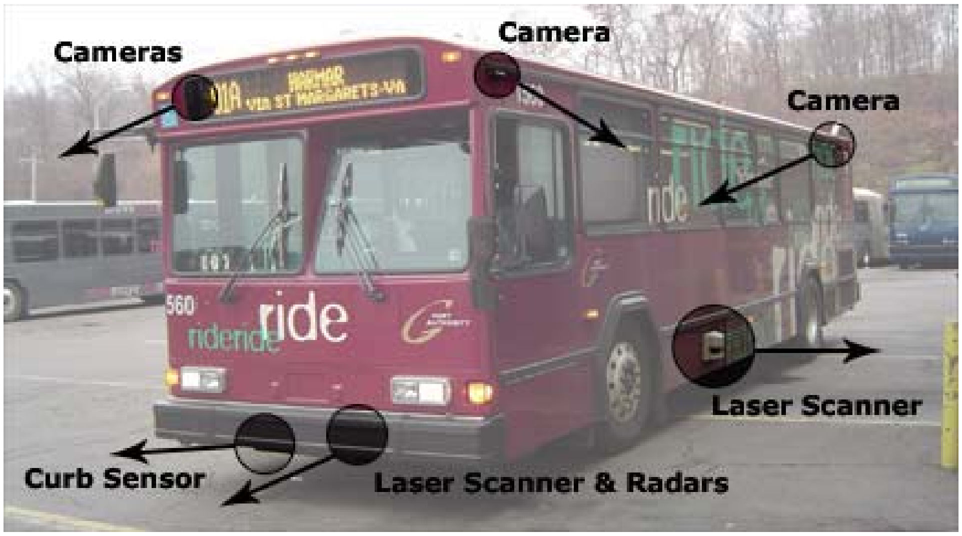

Fig. 1. Installation points and directions for sensors and cameras. Right side is comparable to left side. The two radars are positioned near the bumper corners. The small hole in the bumper for the forward laser scanner is not present in this picture.

transit tasks. Instrument panels are often mounted very low and out of sight for most drivers. Shifts are long, and in a full bus, the passengers create a great deal of noise. Visual search is extensive; bus drivers are required to track many more visual targets in their field of view than their counterparts in passenger vehicles.

Finally, transit operators often encounter risky behavior on the part of nearby drivers and pedestrians. For example, it is not uncommon for vehicles to speed past a bus on the left and then cut in front, only to immediately turn right.

C. *Project Structure*

As previously alluded to, this project includes two geographically separated groups, each comprising of a university, transit agency, and state department of transportation. The side component is primarily being addressed by the Pennsylvania group: the Robotics Institute, Port Authority Transit of Allegheny County, and PennDOT. The forward component is being examined by the California group: California PATH, San Mateo County Transit District, and Caltrans. Gillig, the manufacturer of the buses being equipped (Fig. 1), is involved with both components. Interactions between all seven parties occur regularly and frequently, ranging from global concepting all the way down to arcane technical details.

II. Integrated Concept

The fundamental mission of this project is to develop an *integrated* system where the front and side components share information, work together on specific threats (e.g., handoffs, scenario classification, etc), and provide the user with a coherent, unified view of the system. As such, there are certain features that are best described in context of the integrated system. Many of these features were developed by the ICWS team jointly and are presented here for additional context to the main thrust of this paper.

A. *Sensor Coverage*

The quantity and quality of sensors placed on the ICWS buses are well beyond what would be expected in commercial deployment (Fig. 1). This level of coverage and installation was undertaken in order to ensure that success in the basic task of collision warning was not hampered by improper estimations of commercial sensor capabilities. Many of the cameras were installed for the purpose of validating system performance. The main sensors on the buses are the laser scanners (3), radars (2), curb sensor, inertial measurement unit, GPS, and direct connections to the in-vehicle data bus.

The sensor coverage (Fig. 2) is partly a function of sensor capability and intentional restriction of warning zones. Notable restrictions of coverage are an intentional restriction of side warnings to the nearest 3m on either side of the bus to reduce the likelihood of false alarms. In reality, objects are detected and tracked starting around 20m. While the PAT bus does not have a bicycle rack (Fig. 1), the SamTrans buses are equipped with fold down front-mounted racks, thus requiring a blind spot for a clear view and to limit false alarms due to vibrations during use.

Threats that pass between regions (e.g., the example provided earlier involving cut-in behavior) can be handed between components to ensure rapid acquisition, scenario classification, and handling of multi-region threats.

B. *Warning Conventions*

There was specific care to utilize multiple levels of warning for both the side and forward components. This practice has been suggested and successfully deployed in other intelligent vehicle research (e.g., [6-9]).

There are two levels for the primary functionality of the system. These are used for both forward and side threats:

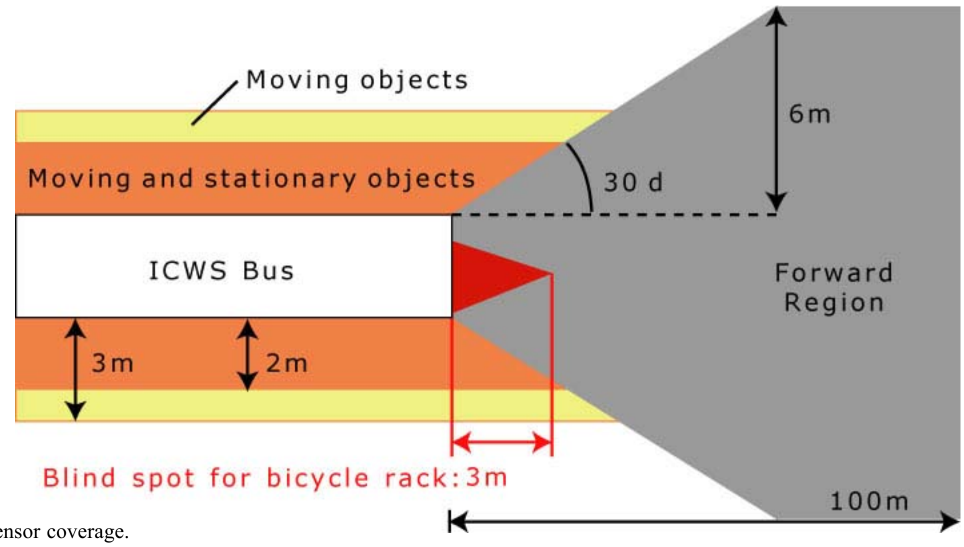

Fig. 2. Sensor coverage.

1) *Alert:* The system has detected a threat with the potential to become more dangerous.
2) *Imminent Warning:* The system has detected a threat with a high probability of making contact with the bus unless evasive action is taken.

Warning priority is within, but not across the three regions (left, front, right). Each region is independent within this scheme. More extensive prioritization of warnings was explored, but not specified due to concerns that a false warning in one region may inadvertently squelch an important warning in another region.

Two secondary, but potentially more dangerous warnings, were also specified. These are specifically focused on the side component, but may eventually be applied to the forward component as well.

3) *Contact:* The system detected a potential side collision. The driver should check mirrors and inspect as necessary.
4) *Under Wheel:* The system detected a potential pedestrian slipping under the bus. The driver should check mirrors and inspect as necessary.

Under Wheel will only trigger at low speeds (i.e., bus stops). These two warning modes are still under development due to the challenge of properly handling the signal detection problems involved. However, these events are of key interest to the team, sponsor, and participating agencies. As such, they are worthy of attention.

C. *Driver Vehicle Interface*

Previous work towards a driver-vehicle interface (DVI) under this program identified three major paradoxes present in transit collision warning interfaces [10]:

1) Drivers agree with the philosophy of earlier action rather than harder action yet they would like as few alerts and warnings as possible.
2) Nighttime drivers prefer audible warnings due to concern over glare while daytime drivers tend to focus on visual warning options.
3) The warning should be salient enough to elicit a driver response but should not be readily noticeable by passengers.

It is important to keep the tradeoffs inherent in these paradoxes in mind when developing such systems. While often suggested by technologists new to the field, vibration displays in the seat or steering wheel have traditionally been strongly discouraged during driver interviews due to long shift durations. Other items of note are concerns that warnings may act as a “starting gun” for fraudulent falls by passengers (a very real problem) and that a high rate of false alarms will lead to severe dissatisfaction with the system.

The DVI design implemented on the ICWS buses integrates the forward and side warning stimuli into a unified display (Fig. 3). The forward portion is an adaptation of a similar design utilized for low visibility snow removal operations [9] while the side warnings were developed specifically for this platform and application. When viewing the DVI the physical “location” of the driver with respect to the spatial representations of the LEDs is in the middle of the two DVI bars, between the lowermost forward LED and the “Side, front” LEDs. The bars are designed for the window pillars immediately in front of the driver, thus providing a peripheral display that does not obscure the driver’s external view of the road scene. The placement also supports rapid checking of the side mirrors – an action much more frequent in transit operations than in regular passenger vehicle operation.

DVI activation is consistent across the forward and side components. As the Under Wheel case is considerably more dangerous than Contact, it has been assigned the red option. The DVI bars include speakers below the triangle LEDs in order to reduce the installation requirements of the

Fig. 3. Integrated DVI. The forward LEDs grow downwards with threat level and "aim" at threat. The triangles point towards the relevant mirrors. Bars are mounted on the pillars of the driver's forward window.

system. The use of sounds to augment the alerts is being examined in related simulator research.

1) *Alert:* Yellow LEDs.
2) *Imminent Warning:* Red LEDs.
3) *Contact:* The triangles for the appropriate side blink yellow.
4) *Under Wheel:* The triangles for the appropriate side blink red.

Driver controls are mounted as a group in the instrument cluster. Volume, brightness, and warning sensitivity (high, medium, low) provide a level of driver control so that individual differences and environmental factors can be accommodated. However, the system is designed so that drivers are not able to use the volume and brightness adjustments to disable the system. Status lights for the three regions (left, front, right) are also provided for quick identification of system health.

III. Side Component Features

A. Flexible Architecture

The side component architecture is composed of many modules [11]. Each module represents a single algorithm or function, such as an object tracking module, a warning algorithm, or a laser data logger. Each module can be thought of as a single process with abstract inputs and abstract outputs. Thus, each module can be developed individually with inputs coming from the unified, time tagged, data logging and replay system and outputs going either to log files or graphical displays. Once a module has been sufficiently tested, it can be (transparently to the module developer) integrated into the full system by using inputs and outputs that communicate via shared memory or socket communications to other modules in the system.

In addition, while in individual development a module reads its parameters from a local file, when running in the integrated system, a module transparently gets its parameters from a central repository. This repository allows the team to consistently manage this kind of configuration information and provides a central point of control. The repository is managed by a scripted program which is responsible for starting up all of the necessary modules and which monitors the health of those modules as they run. The repository manager recognizes when there are problems in the system and attempts to either restart individual portions of the system, or to restart the system as a whole when there are more serious errors.

B. Object Detection and Tracking

The raw data of sensors typically needs to be analyzed and processed in order to provide relevant information for a given application. When moving objects are present, they filtered out and tracked using algorithms for Detecting And Tracking of Moving Objects (DATMO, e.g., [12, 13]). By tracking objects over time, these algorithms estimate object position, velocity, acceleration and angular velocity (turn rate). The result of these methods is an immediate map of the sensed region of fixed and moving objects with knowledge of key properties.

The side laser scanners provide fairly reliable range readings with 1° or better angular resolution. However, in order to predict collisions, the warning module needs object tracks: a listing of the distinct moving objects and their estimated current motion. Since the laser scanner does not measure speed, motion must be detected by the change in position between scans. To achieve this, DATMO is divided into the following steps:

1) *Convert* the scan data into points in the fixed world coordinate system, segmenting contiguous clusters of points into objects.
2) *Extract* linear features, and classify the segments according to their shape: rectangular or line (car, wall, etc.), compact (pedestrian), other (bushes, crowds, etc.)
3) *Associate* segments with existing tracks based on proximity and similarity. This step utilizes a Kalman filter to estimate object motion from the change in feature position and orientation.

The primary technical challenge is to extract stable object features and determine which features correspond in consecutive scans, yet use less than 7ms of processor time.

Included into this step is a laser line striper for curb tracking [14, 15]. This provides a clear indication within the internal map for sidewalk edges and therefore a boundary for safe pedestrian behavior. The laser line striper consists of a laser and a camera separated by a known distance. The camera views the laser line projected onto the observed object and the system determines distance and shape by triangulation.

C. Threat Calculations

The sensors and modules described in the previous sections provide the dynamic quantities of the bus and the observed objects and additional information about the environment. These measurements are combined with preloaded information to analyze the threat level of the situation. In the warning algorithm the system calculates the probability that a collision will occur within the next five seconds. If the probability of collision exceeds a certain threshold, an appropriate warning is displayed to the driver. A detailed description of the algorithm can be found in [16]. A short example is illustrated here.

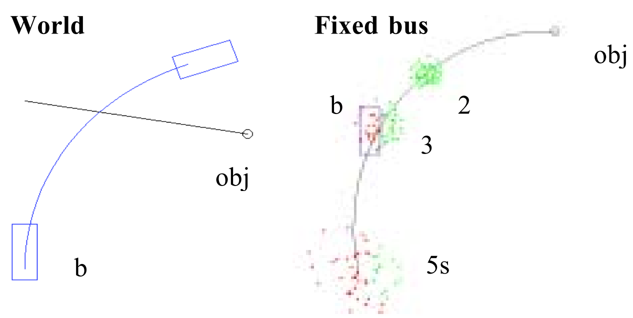

Fig. 4. The trajectories of a bus (b) and an object (obj) shown in the world coordinate frame (left) and the fixed bus frame (right). In the right figure possible positions of the object are shown for the times 2, 3, and 5 seconds in the future. Green indicates that no collision has happened; red indicates that a collision has happened.

In Fig. 4 a bus turns right while an object crosses its path from right to left (World). The sensors measure the speed and turn rate of the bus and the location and velocity of the object. The algorithm calculates possible paths of the object with respect to the bus (Fixed bus). In this calculation the paths are distributed according to the uncertainties of the measured dynamic quantities as well as according to simple bounding models of driver and object behavior [16]. Next, the system determines for times up to 5 seconds into the future which fraction of these paths lead to a collision. In Fig. 4 this is shown for the times 2, 3, and 5 seconds. This fraction is the probability of collision and is plotted versus time (Fig. 5). This graph is divided into three areas, each a different level of threat severity. The area with the severest level that the probability of collision curve reaches determines the warning issued to the driver.

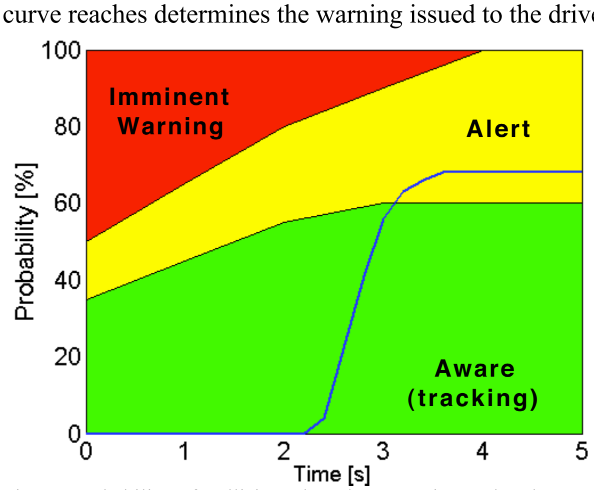

Fig. 5. Probability of collision plotted versus time. The three regions correspond to the warning levels aware, alert, and imminent.

The algorithm can also deal with environmental information. For example, if the object is a pedestrian and is on the sidewalk, there is an enhanced likelihood that the pedestrian will stay on the sidewalk. This is addressed by giving the paths leaving the sidewalk a lower weight.

D. *Self Preservation*

The SICK laser sensors on the sides of the bus increase the vehicle width beyond what drivers are accustomed to and could therefore accidentally come in contact with objects during tight maneuvering. Cheaper, smaller sensors are needed for commercial deployment but were not available at the time of sensor selection. As such, a special "flinch" mechanism was utilized to enable the SICK sensors to rapidly retract out of harms way should an object pose a specific threat to the sensor itself (Fig. 6).

Fig. 6. Side laser extended (operation) and retracted (flinch, fail, or off).

The hinge is on the leading edge so that the sensor will recoil should the software not initiate a flinch and a grazing strike occurs. The SICK will retract when the system is not on and fails into retracted mode.

IV. Future Project Plans

A. *Integrated Field Test*

Two buses, one at each transit agency, have been equipped with both the side and forward components. This will allow examination of performance in multiple agencies, various environmental conditions (snow, fog, etc.), driving conditions (dense urban, highway, suburban, winding rural, etc.), and regional conditions (driver and pedestrian behavior, rush hour patterns, etc).

System installation occurred during the early months of 2004. After an initial system shakedown period and baseline driving data collection period, the DVIs will be activated and testing of the system in revenue service will begin. This deployment will continue for approximately one year under the ICWS project.

B. *Integrated Evaluation*

Given the fact that little is known about how integrated warnings will affect transit safety, the evaluation phase of this project is particularly interested in multi-region events. In particular, what happens when there are multiple simultaneous or sequential threats? For the latter, the bus may be rounding a corner when a side warning informs the driver they may rub the side of the bus against an obstacle, thus leading to the driver straightening out and triggering a forward collision warning for a parked car across the street.

The research plan is to collect data in cycles of baseline and test conditions. In both cases the system will be on but the DVI will only be on for the test conditions. This will allow comparison within drivers and longitudinally, thus permitting analysis on system benefit, dependency, and behavior shifts. Development code freezes will be instituted to prevent mid-condition system performance shifts.

C. Commercialization and Deployment

As previously alluded to, a major intention of this program is to spur commercialization and deployment of transit collision warning systems. To this end, detailed performance specifications are being compiled for dissemination following completion of the project. The specifications are refinements of and expansions upon similar documentation produced during the precursor projects [2, 3] and will benefit from findings from the integrated field test and evaluation as well as technology advances by the team. The final integrated performance specifications will be in a form that the transit industry and suppliers can follow to reproduce and integrate collision warning systems for the industry.

Other efforts within the program are underway in support of this thrust. Clever Devices [17] has deployed and tested their Enhanced Object Detection System at Port Authority Transit and is the process of releasing Seymor, the market ready version based on the lessons learned during their field tests [18, 19]. Also, the California group has convened a Bay Area Regional Advisory Committee of local transit agencies to generate inputs on an acceptable system and is actively exploring commercialization and deployment opportunities beyond this project.

V. Conclusion

This paper only documents a small portion of the work being developed for the integrated warning system as a whole, much less the side component. What has become uniformly clear to all project participants is that the problem of providing appropriate collision warnings in a transit environment is exceptionally difficult. However, considerable progress has been made and the team is now deploying prototype systems on buses for testing in revenue service. The findings from this project will provide not only insight to the benefit, requirements, and effectiveness of such systems, but also detailed data about the environment in which transit buses operate.

Acknowledgment

Dan DeBone and Robin Rochez from the Port Authority Transit (PAT) of Allegheny County and Frank Burton of the San Mateo County Transit District (SamTrans) provided considerable assistance with installation and deployment of the system and insight on real world transit activities.

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