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Side Collision Warning Systems for Transit Buses

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Abstract

Transit buses are involved in many more accidents than other vehicles. Collision Warning Systems (CWS) are therefore placed most efficiently on these buses. In our project, we investigate their operating environment and available technologies to develop performance specifications for such CWS. This paper discusses our findings of transit buses driving through very cluttered surroundings and being involved in many different types of accidents where currently available CWS do not work effectively. One of the focuses of our work is pedestrians around the bus and their detection.

Keywords collision avoidance, transit bus, safety, sensors.

1 Transit Bus Side Collisions

The goal of our project is to build intelligent vehicle systems to reduce side collisions in transit buses. Transit buses are already a very safe mode of transportation: the passenger-fatality rate per passenger-mile is about 15 times smaller than the equivalent rate for other vehicles [1]. The sheer size of a bus helps to protect the passengers and buses are driven by professionals, working regular shifts over known routes, and typically operate at low speeds. Although this fatality rate is very low, the probability that a particular bus will be involved in an accident during a year is much higher (about 15 times) than the same probability for other vehicles [1] because buses operate many hours per year and typically operate in very congested urban areas, and by the nature of their job are often in close proximity to pedestrians. A CWS mounted on a transit bus can therefore potentially prevent many more accidents than one mounted on another vehicle. The installation of a CWS is made easier by the fact that an "electronic infrastructure" is already present in modern buses, since buses carry increasingly sophisticated electronics, with positioning systems and digital communications to better estimate time of arrival along their route.

The USDOT Federal Transit Administration is sponsoring three projects to reduce bus collisions, as part of the Intelligent Vehicle Initiative (IVI). One project headed by UC Berkeley / PATH is working on forward-looking sensors, to reduce the number of collisions where the bus strikes the rear end of a lead vehicle. Another project not yet under way will work on the complementary problem, putting sensors and alarms on the rear of the bus, facing backwards, to try to warn drivers of vehicles that may not have noticed that a bus has come to a stop. Our project, in partnership with Pennsylvania Department of Transportation (PennDOT) and the Port Authority of Allegheny County (PAT), is looking at the problem of side collisions[1].

Side Collisions Warning Systems (SCWS) have already been developed for other types of vehicles, notably for Class 8 trucks. For heavy trucks, the problem these sensors are designed to alleviate is the driver not seeing a car and causing a collision while changing lanes. The SCWS systems use sonar or radar to look in adjacent lanes and then warn the driver of the presence of a car. Typically, the warning comes in two phases. While the truck is driving straight, if the SCWS detects a vehicle along side the truck, it illuminates an indicator built into the side mirrors, as a situation awareness aid. If the driver puts on his turn signal, indicating an immediate intent to change lanes, the SCWS switches from situation awareness mode to collision warning mode. Then, if there is another vehicle along the truck, the SCWS uses an audible warning tone in addition to the light in the mirror.

SCWS are also commercially available for cars. Because most car owners are not willing to pay a lot of money for SCWS and the blind spot of cars is much smaller than the blind spot of trucks SCWS for cars

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1 Further details on the FTA program may be found on their web site, www.fta.dot.gov/research/safe/ivi/ivi.htm.

usually have infrared proximity sensors and cover only the few square meters of the blind spot.

In the summer of 1998, we did a small study to understand the applicability of these technologies in a transit context. We installed both rear-looking and commercial side-looking CWS on a PAT transit bus (Figure 1). As a demonstration, the systems were very successful. The rear-looking system illustrated the potential for detecting cars approaching from the rear; it was connected to a variable message sign on the back of the bus warning the driver to "slow down!", followed by an air horn for truly inattentive drivers. The side-looking system used 4 sonars along the side of the bus to detect pedestrians and to warn the driver. The demonstration was well received, and led to the full-scale research projects now under way.

Figure 1 Transit bus with rear-looking and side collision warning systems (small black box, indicated by the arrow).

However when PAT put the demo bus into service with the side warning system enabled, several flaws became rapidly apparent. First, the sonar would miss important objects. The demo set-up had only 4 sensors spaced along the side of a 40-foot bus. This is adequate for a truck application, looking for a car in the adjacent lane, since cars are typically at least 15 feet long and therefore could not get lost in between sensors. But for the bus application, the targets of interest include much narrower objects, such as pedestrians, lampposts, mail boxes, signs, trees, etc.

More significantly, the interface as configured generated an extremely high number of nuisance alarms. For the truck application, the sensors are configured to cover a lane width, approximately 4 meters. Any object within that range would cause the light in the mirror to illuminate, or, if the turn signal were on, the audible tone to go off. Buses usually operate in the curb lane of urban streets, and are therefore very often within 4 meters of mail boxes, traffic signals, pedestrians, parking meters, and parked cars. Worse, every time the bus stops to pick up or discharge passengers, the driver turns on the four-way flashers. In the demo bus, this triggered the audible alarm. So just when the bus driver knew that the bus would be operating close to pedestrians at a bus stop, the alarm would go off, disturbing the driver and potentially alarming passengers. Figure 2 shows how much "clutter", people as well as objects, can be found very close to the bus.

Figure 2 Operating environment of a transit bus. The picture is taken from the top rear right corner of the bus, looking down along the side of the bus, which is visible in the left part of the image. The bus has just left a bus stop and is only one foot away from the curb. Two to three feet away are people and objects.

Clearly, the commercial systems designed for trucks cannot be simply adapted for transit buses. It is necessary to study in detail all the factors contributing to bus collisions and find ways to have a SCWS, which effectively identifies dangerous situations without causing too many false alarms. Our research project therefore has several phases:

A. Analyse available incident data.
B. Establish functional goals for a SCWS.
C. Assess existing SCWS.
D. Develop preliminary performance specifications for a SCWS.
E. Investigate state of the art technology.
F. Select test system.
G. Construct/acquire collision warning systems.
H. Conduct testing to validate performance specifications.
I. Finalize performance specifications for SCWS.

We are now approximately one quarter the way through the project. We have completed most of the analysis of the transit environment, and have several results on sensors.

This paper reports on what we have found about the transit environment, the number and kinds of accidents in which buses are involved, the coverage area of a CWS, our preliminary work on sensors, and our plan for further research.

2 Magnitude of the Problem

In order to better understand the operating environment of transit buses and find the relevant factors for bus crashes, we studied accident statistics from Washington State [2], accident reports from PAT, and data from the Fatality Analysis Reporting System (FARS)[2].

There are several conclusions from our analysis that make the design of SCWS for transit buses unique:

1. Many of the most serious accidents involve pedestrians. All of the other research projects in the USDOT IVI program focus on collisions between vehicles, or between vehicles and fixed objects. Pedestrians are harder to detect than vehicles, and are much harder to predict.
2. Only a very small percentage of side collisions are classical lane change / merge accidents. Buses have a much wider variety of collision types than other vehicles.
3. Many of the bus accidents involve objects approaching from the side; side-looking sensors are thus an important part of a collision reduction strategy. There is a wide variety of ranges, speeds, and object sizes in these collisions, so a single sensor might not be adequate for the task.
4. The line between safe and unsafe situations is very tight. It may not be possible to warn the driver in time to avoid a collision without generating too many nuisance alarms; instead, it may be better to design a situation awareness system.

Accident Statistics

Weather, lighting condition, time of day, day of week, season, age of driver, and age of pedestrian hit do not play a factor or are too small a factor to be relevant.

Table 1 shows statistics about the number of collisions involving transit buses and the resulting fatalities [3].

Collisions with	incidents	fatalities
Other Vehicles	24640	64
Objects	2280	3
Pedestrian	959	43
Totals	27879	110

Table 1 Bus collisions and fatalities per year 1994-1997.

There are approximately 25 times more bus-vehicle collisions than bus-pedestrian collisions, even the number of collisions with objects is more than twice as large than the number of pedestrian collisions. But the number of fatalities is comparable for both, pedestrian and vehicle collisions, the number of fatalities resulting form a collision with objects is very small. This high number of pedestrian fatalities stresses the importance of pedestrian detection, a problem not addressed by currently available CWS. In our analysis we paid special attention to pedestrians.

In one quarter of all fatalities the pedestrian is partially or completely underneath the bus. It is therefore important to monitor underneath the bus, an area, which is not covered by any currently available CWS.

In about 12% of all bus-pedestrian collisions does the bus driver "hit and run", but does so only in 3% of bus-car and 1% in bus-truck collisions. This is best explained by assuming, that the bus driver simply doesn't notice the incident happening. This is supported by the accident reports of the PAT bus drivers, where they often state that they have no knowledge of a bus-pedestrian incident or that a passenger or bystander informed them of the incident. A warning system should therefore not only warn of potential dangerous situations, but also inform the driver when contact with a vehicle, object, and especially with a person has been made.

In more than half of all incidents the bus driver did not commit any violation, whereas for the other drivers this is only the case in 17% of the incidents. Evidence of alcohol and drug usage by the bus driver is virtually completely absent, in contrast to car drivers (2.5% of all cases) and notably pedestrians (23%). This emphasizes another challenge for a CWS, it is most times not the bus driver who creates the dangerous situation and so the dangerous situation needs to be identified by looking at the behaviour of the other party.

Table 2 shows different collision types and their relative significance with respect to number of collisions, property damage, injuries, and fatalities. The number of fatalities is too low to make statistical significant statements. But what can be observed is that most fatalities are bus-pedestrian collisions. Otherwise the fatalities are fairly evenly distributed over the range of collision types. It should be noted, that the collision type "lane change/merge", which is the most significant one for truck and car CWS, are only about 6% of the cases for buses.

In order to see how resources can be used most efficiently and what the cost savings of CWS are, the social costs of bus accidents have been estimated. They are roughly $8000 per bus per year [4]. Even with a modest 10% reduction of collisions a several thousand dollar CWS will amortize itself within a few years.

Other Observations About the Bus Environment

One of the challenges for a CWS is to suppress false alarms. A bus often drives very close to the curb and is only 1 or 2 meters away from parked cars, signposts,

[2] Data accessible through www-fars.nhtsa.dot.gov.

collision type	Collision		property damage		non-disabling injury		disabling injury		fatal	
	#	%	$1k	%	#	%	#	%	#	%
off road or parked car	305	10.0	613	8.4	8	2.9	4	4	1	5.9
rear end	625	20.6	1729	23.7	89	32.4	29	29	2	11.8
lane change/merge	179	5.9	375	5.1	6	2.2	3	3	0	0.0
Sideswipe	430	14.1	905	12.4	12	4.4	6	6	0	0.0
opposite direction	134	4.4	512	7.0	18	6.5	9	9	2	11.8
same direction, one turning	243	8.0	437	6.0	9	3.3	1	1	0	0.0
entering or leaving parked position or driveway	297	9.8	638	8.7	12	4.4	4	4	0	0.0
entering at angle	594	19.5	1849	25.3	65	23.6	22	22	3	17.6
collision with pedestrian	84	2.8	9	0.1	35	12.7	13	13	8	47.1
Other	148	4.9	239	3.3	21	7.6	9	9	1	5.9

Table 2 Relative weights of bus collision types in Washington State, 1990-1995 [2].

trees, pedestrian, etc. When picking up or dropping off passengers the bus sometimes even touches the curb and people and objects can be only a foot or so away from the bus (see Figure 2). All this visual clutter has the potential to cause many false alarms. We believe that an effective way to avoid those false alarms is to detect the curb and determine if the objects or pedestrians are on the sidewalk. If they are on the sidewalk an alarm does not need to be generated. Similarly pedestrians might be considered safe if they are standing between parked cars.

3 Collision types and coverage areas

A more detailed look at the data from Table 2 reveals that about 75% of all collisions could have been detected by side looking sensor. It also tells us, that there is a great variety of collision types, therefore a simple approach is not possible.

In more detail, the following types of collisions are detectable by a side-looking sensor: off road, lane change / merge, sideswipe, entering or leaving parked positions, entering at an angle, and collision with a pedestrian. In some of those cases, such as hitting an object off the road, the impact may be on the front of the bus; but a side-looking sensor, capable of detecting the curb, is the easiest way to detect that the bus is in a dangerous situation. In other cases, such as lane change/merge, the impact may be with an overtaking vehicle, so the sensor would have to look to the rear as well as to the side. The range of a side-looking sensor may need to go as small as a few inches; or as far as many tens of meters, to detect a high-speed overtaking vehicle.

It is worth singling out for attention that the classic lane change/merge accident, for which commercial sensors are designed, accounts for about 6% of the total number of bus accidents, and none of the fatalities in our sample.

The area the sensors need to cover is first of all the blind spots. Figure 3 shows the field of views of the bus driver. It should be noted that the coverage of the right side mirror is quite limited, it makes only a small area close to the bus visible to the driver. The coverage is much more limited than the coverage from the left side mirror because of the greater distance between driver and mirror. Many buses have a second mirror for each side with a convex surface giving the driver a larger field of view. But it is very difficult to estimate distances with the convex mirror and it is therefore hard to judge if a situation is dangerous. It also needs to be mentioned that the right side mirror is sometimes obstructed by passengers standing in the bus close to the door, either because the bus is full beyond capacity or because passengers are slow to move to the back of the bus.

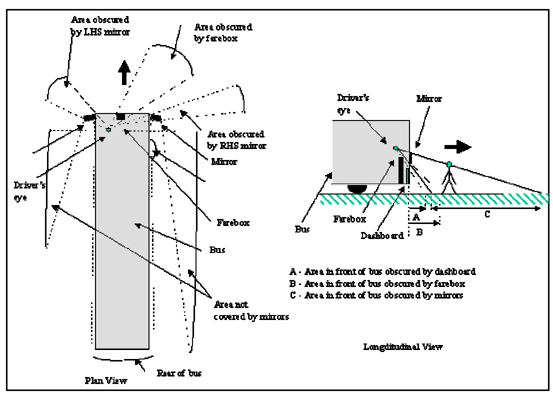

Figure 3 Field of view of a bus driver. Note the very limited FOV in the side mirrors, and the occluded areas that are blocked by the mirrors, the dash, and the till.

4 Sensing

The discussions in the previous sections tell us what a CWS need to be able to do. To summarize, an ideal CWS for a transit bus should have the following capabilities:

1. Detect objects underneath the bus (at least in front of the tires).

2. Full 360-degree coverage around the bus at very short distances, especially in front and to the right side.
3. Side and rear coverage for lane change manoeuvres.
4. High resolution - approximately 1 inch at 6 feet for curb detection.
5. Distinguish cars from pedestrians.
6. Spot rapidly approaching vehicles at longer distances.
7. Estimate velocity of vehicles and pedestrians.
8. The sensor system should not be too expensive (< $5,000)
9. Few sensors
10. Reliable, easy to maintain, and easy to use

It is likely that no single sensor can fulfil all these requirements. We are investigating a number of sensor systems. One suite of sensors that is potentially useful is based on video sensing. It has the following characteristics:

1. Stereo cameras for 3D coverage and identification
Using two cameras in a stereo configuration is sufficient to obtain 3-D information, especially the range to the object [5]. Monitoring the objects location over time lets one calculate the velocity. This can be accomplished even while the bus is in motion. With the help of recognition programs it is possible to identify people, objects, and vehicles as such. This information would be input to the warning algorithm software for use in alerting the operator when necessary. A stereo camera pair may also be sufficient for a detection system for vehicles approaching too rapidly from the rear.

2. Video and laser diode for curb and close object detection
A single video camera gives a 2-D picture. By using the fanned-out light of a low poser laser to produce a thin line of light and having a camera monitoring this line from a certain distance one can obtain a sensor of high resolution. This sensor will mainly be used to detect the curb, but it also gives information about objects close to the bus. The working principle is shown in Figure 4.

3. Single cameras as a visual aid.
While the detailed design of a user interface is beyond the current point of our work, it would be easy to use the video data directly in the user interface. Video cameras can monitor the blind spots with the video image directly displayed to the bus operator. Light sources, e.g. IR light from diodes, may be added to further illuminate the outside scene. Cameras by themselves are passive, i.e. they cannot produce warnings. It is up to the operator to judge the situation based on the video display. The dual usage of video both for the operator and the computer for usage in generating warnings gives the operator a much larger amount of information for safer operation. In a typical situation, a stereo or video + laser sensor could trigger a situation alert, and the driver could then examine the appropriate video image to assess the severity of the threat.

5 Future work

There are a few things about the accident statistics, which we still want to investigate. We want to find out if there is any correlation between the indicators being on and side collisions. In other words, is it sensible to include the status of the indicator in the trigger for the alarm? Furthermore we are trying to get information about near misses. We will address these issues by having bus drivers fill our questionnaires with questions related to accidents they have been involved in and dangerous situations they encounter frequently.

We have started to build and test a sensor system described in the previous section. We will try to find the optimal configuration of video cameras and laser diodes and test the system first by mounting it on a van and then on a transit bus while it is in operation.

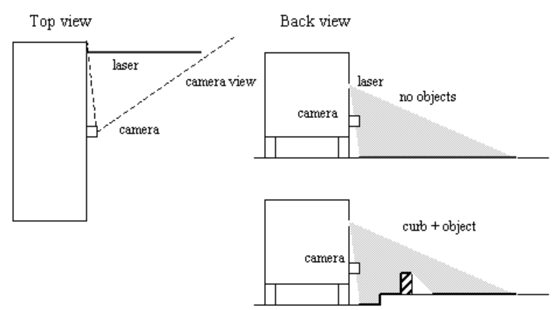

Figure 4 Video and laser diode as sensor system. The line projected by the laser is indicated as a thick line, the grey area is the plane in which objects can be detected.

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