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Intelligent Safety and Driver Assistance Systems for Heavy Duty Trucks

Volkmar Gross
Portland State University

Ziad Keirouz
Portland State University

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Abstract

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Intelligent Safety and Driver Assistance Systems for Heavy Duty Trucks

Project Team: Volkmar Gross, Ziad Keirouz

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Contents

1. Preface

The number of commercial vehicles (trucks) on the U.S. Highways will continue to growth by an average annual rate of approximately 10% over the next 3 to 5 years. Along with the predicted increased movement of goods due to the e-commerce revolution, accidents (and death rates) involving commercial trucks are on the rise. In the following, we will investigate the future of Intelligent Safety and Driver Assistance Systems, designed to increase the overall safety of commercial vehicles, in the wake of augmented national and government interest in these technologies. We will concentrate on vehicle-based rather than infrastructure- based technologies. Due to the large number of different systems under development, we have to restrict our investigation. Therefore, we will intentionally disregard all kinds of Vision Enhancement systems (like Night Vision) as well as all infrastructure-assisted approaches including GPS-based technologies.

2. Background

2.1 Statistics

In the United States occur about 25 million vehicle crashes each year, most fender benders. However, some 42,000 people die and four million are injured seriously enough to end up in emergency rooms. According to a study of the American Trucking Association (ATA), passenger cars travel an average of 11,500 miles per year, whereas trucks (class 8) travel an average of 67,000 miles per year, 6 times the average car mileage[1].

The same study unveils that trucks had a crash rate of 2.16 per million miles traveled, while cars had the second highest rate (5.53) after motorcycles (6.76). The Federal Highway Administration (FHWA) reports that, between 1987 and 1997, the fatal crash rate for large trucks dropped 33%, while miles traveled increased 43%[1]. Crash statistics accumulated by the National Highway Traffic Safety Administration (NHTSA) over the last five years indicate that crashes involving trucks have killed more than 25,000 people and injured more than 640,000 - a rate of 14 deaths and 35 injuries a day. According to NHTSA, the Police assigned in 71% of all accidents with trucks and passenger cars involved one or more errors to the car driver and none to the truck driver.

The University of Michigan Transportation Research Institute (UMTRI) studied 5,500 fatal crashes involving a truck and a passenger vehicle[2]. In 70% of the accidents investigated, the car drivers were responsible for the accidents, while truck drivers were responsible for 16% of the crashes. These results confirm the outcome of an earlier UMTRI study published in 1998.

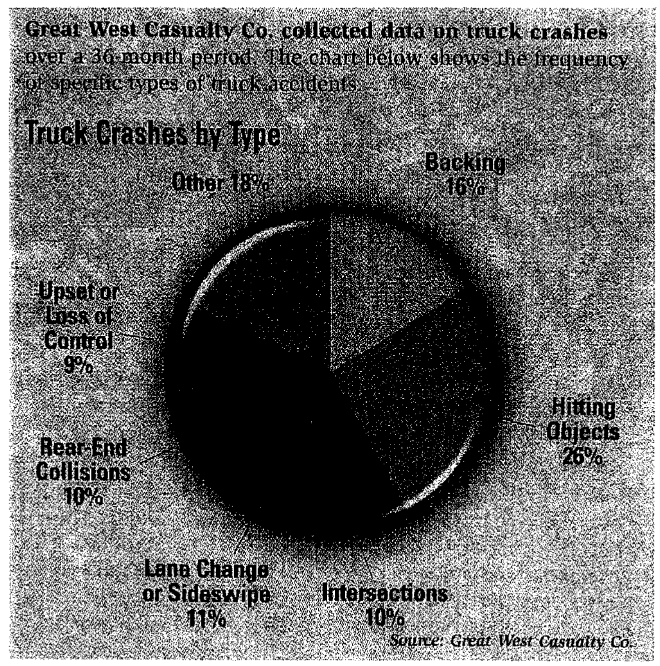

Figure 1: Crashes by Type

British Columbia based Technical Services, a forensic engineering and crash reconstruction firm that specializes in large truck crashes states that an average of 600 Class 8 truck drivers die every year in highway accidents - 55% in rollovers and 10% in fuel oil fires[1].

Figure 1 shows the frequency of specific types of truck accidents, collected by Great West Casualty Co. over a 36-month period[3].

2.2 Legislature

The authority and responsibility for highway safety (i.e. vehicle, driver, passenger, roads etc.) is shared between the NHSTA and the FHWA. While NHTSA focuses in terms of highway safety on the vehicle, the driver and the occupant aspects, the roadway itself is in the responsibility of the FHWA. It also regulates vehicles engaged in interstate commerce and has thereby authority over vehicle manufacturers

On November 18, 1999 the U.S. Congress approved H.R. 3419, the Motor Carrier Safety Improvement Act of 1999, which is widely considered to be a comprehensive bill to push and improve overall truck safety[4]. One of the key provisions under this act is the establishment of a Federal Motor Carrier Administration within the Department of Transportation , in particular responsible for truck and bus safety, with authority and visibility equal to the Federal Aviation Administration and the Federal Railroad Administration. In the past, the DOT's Safety Program has been run out of an office in the FHWA. After the House passed H.R. 3419, U.S. Secretary of Transportation Rodney Slater changed his former position and is now supporting it. Previously, Slater held that DOT's safety program should stay where it was in FHWA. The ultimate goal of the safety plan is to reduce motor carrier traffic deaths by 50% over the next 10 years by teaming up with safety groups, industry and federal, state and local governments[3]. The Federal Government hopes that new high-tech systems will play an important role and offer a substantial edge in safety. The Department of Transportation has allocated $12.7 million for four projects under the Intelligent Vehicle Initiative[4]. The grants, combined with $7.7 million from industry partners, will fund tests of large-truck systems addressing rollover, rear-end collisions, roadway departure collisions, advanced braking and hazard warning. The IVI is a component of the federal transportation agency's Intelligent Transportation Systems program (ITS), authorized in the 1998 Transportation Equity Act. Its purpose is to accelerate system advances into the consumer market.

2.3 Industry

Truck technology is being driven by various forces as diverse as electronic commerce, regulations, the shortage of qualified drivers, and even congestion[5]. One reason why NHTSA hasn't been focusing on truck safety in the past is that the industry is already taking the lead. Heavy truck crashworthiness has improved dramatically ~~improved~~ in the past few years without the prodding of government regulations. Currently, there is a tendency among the OEM's to offer exclusive safety related technologies in order to gain competitive advantage, but differentiation appears to be difficult for truck OEM's because of their inability to establish long-term, exclusive relationships with suppliers in North America. Freightliner Corporation recently introduced (announced ???) five technology-based safety-related systems available on future Freightliner Trucks[5]. As part of the federal government's IVI project, some truck OEM's and fleets will participate in extended fleet testing of several safety technologies over the next three years[6]. The vehicle-based systems under investigation include Collision Warning (Eaton-Vorad, Volvo), Rollover Stability (Meritor Wabco, UMTRI, Road User International, Freightliner) and Road Hazard Warning (?, Mack).

3. The State of the Art

3.1 The Progress of Key Technologies

The development of new safety and assistance systems for vehicles in general has been strongly affected or even driven by the rapid progress in some of the enabling technologies, such as Microelectronics (Micro- and Digital Signal Processors, Flash Memory), Sensors (i.e. Image, Microwave, Gyro...), the Global Positioning System (GPS) and the Internet. Especially the processing power of micro processors at hand today as well as the Flash RAM technology made some systems, like image processing- based technologies, now feasible for in-vehicle applications which had been still out of reach just a couple of years ago. The evolvement of new industry standards (hard- and software) for on- board data buses, in particular designed for heavy duty trucks, contributed to the appearance of the current ("Dominant Design") systems architecture inherent in almost all new intelligent vehicle systems, the Electronic Control Unit (ECU) concept. In here vehicle sub-systems (i.e. engine, transmission, brakes, Collision Warning etc.) are being controlled by a tailored control unit, the ECU, that is connected to the vehicle data bus in order to communicate and share available information with other units. Thus, service and diagnostics procedures could capitalize from those innovations and look much different today than in the past.

3.2 Systems available on the Market

3.2.1 Collision Warning (forward-looking CW)

CW systems are in general based on microwave radar technology (24 GHz or 77 GHz) previously developed in the aerospace industry, but are adapted to the special needs implied by the use in ground vehicles. A radar antenna is mounted at the front section of a vehicle, integrated in the bumper for instance. By transmitting and receiving low-power microwave energy, the system can track moving or stationary objects while scanning continuously up to 350 feet up the road ahead. The microwave signals bounce back from objects in the scanned area and can than be analyzed in an ECU in order to gain some information about the obstacles in the path, like their distance, azimuth angle and relative velocity. If necessary, both visible and audible warning messages will be generated at the dash to alert the driver. Figure 2 illustrates the basic Collision Warning system.

A Collision Warning systems like the one described above is been available from one manufacturer since 1994[8], but has been subject to several major upgrades in between. The cost per system to the customer (truck owner) can range from $3,000 up to $ 7,000, depending on the selected options. There are efforts to realize Collision Warning systems with similar performance at considerable lower costs using Laser-Radar, but the propagation of the usually used IR-beams under certain weather conditions (rain, snow, fog) seems to be a critical or even the limiting factor for the success of such attempts.

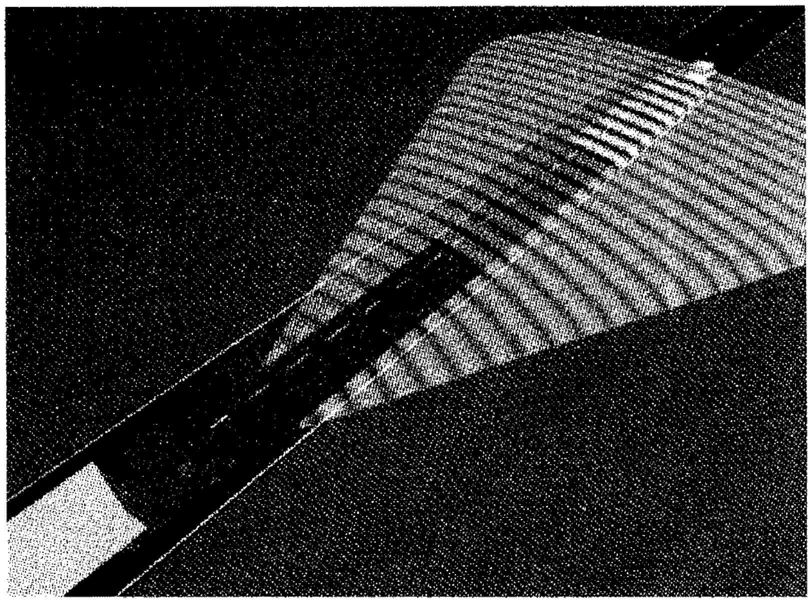

Figure 2: Collision Warning System

3.2.2 Blind Spot Detection and 360° Collision Warning

There are various short-range collision-warning systems from other manufacturers out on the market. They are based on ultrasound, infrared, video or microwave technologies and scan the sides and/or rear of the vehicle, addressing the "blind spots" around the vehicle, which a driver cannot oversee with his eyes (see Fig.3). Some are designed to operate just in low-speed operations like backing and docking situations.

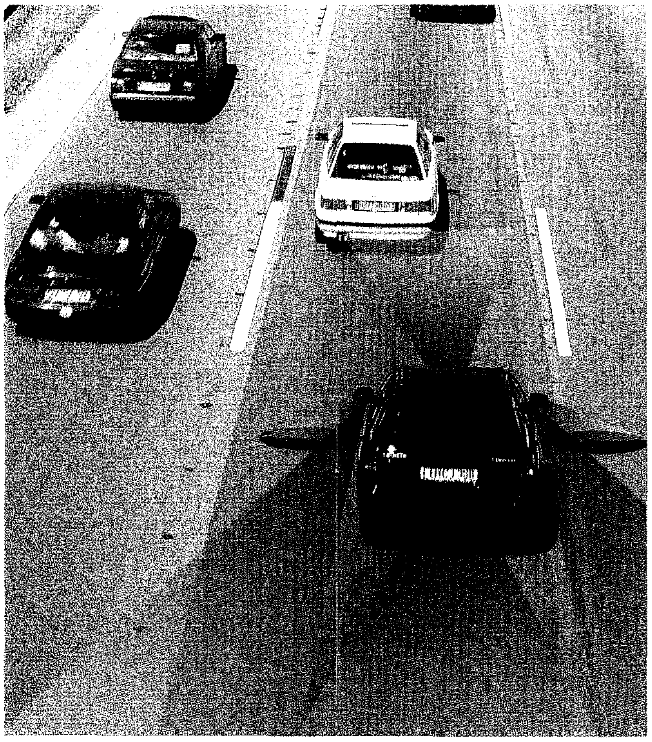

Figure 3: Blind Spot Detection / 360° CW

3.3 Technologies at the Threshold to the Market

3.3.1 Lane Departure Warning

In the first commercial available application of real-time image processing in vehicles, a windshield-mounted camera "watches" the road and a computer determines when a truck comes to close to lane markings or when it drifts out of a lane without applying a turn signal. If this happens, a warning sound ("rumble-strip sound") is emitted from one of

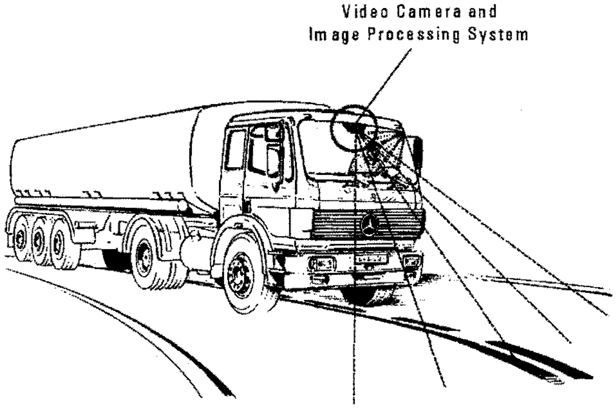

Figure 4: Lane Departure Warning

the speakers mounted on either side of the driver, depending on which side the drift is occurring.

3.3.2 Adaptive (Autonomous) Cruise Control

By connecting the Collision Avoidance or -Warning Radar to the throttle control, engine brake and cruise control, Adaptive (or Autonomous) Cruise Control is able to reduce the truck's speed as traffic slows ahead, thus maintaining a safe headway, and then automatically return the truck to the set cruise speed as traffic speeds up. Collision Warning as described above is one demanded standard feature of Autonomous Cruise Control. Tracking preceding vehicles through curves in the road as shown in the lower part of Fig. 4 is one of the key performance criteria of Adaptive Cruise Control.

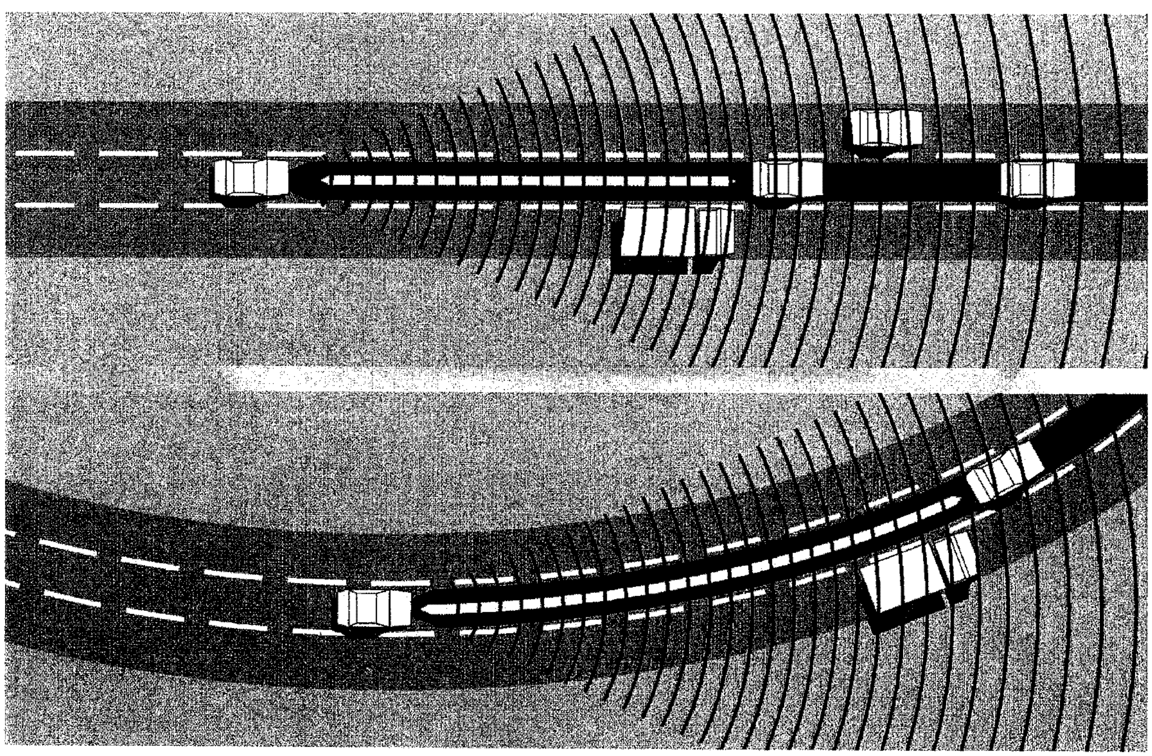

Figure 5: Adaptive (Autonomous) Cruise Control

3.3.3 Rollover-Warning / Control

The concept involves real-time sensing and computation for estimating the roll-stability level of a heavy duty vehicle combination and for continuously tracking how this level is being challenged by the driver's control actions, as the vehicle travels down the road. The computed result constitutes a *rollover margin* that expresses the proximity to rollover. The systems then employs a display interface that advises the truck driver when a narrow-margin event has just occurred, while underway. The sensor output signals are processed through a form of *system-identification* algorithm in order to derive the basis for the display. In it's simplest form, the algorithm can simply be a look-up table. A more ambitious approach involves running computations which derive many parametric values for an embedded roll model of the vehicle.

Figure 6: Rollover Accident

3.4 New Technologies (in R&D)

3.4.1 Electronic Tow Bar (Platooning)

The Electronic Tow Bar is one of the systems which have been developed in the European Prometheus Project, a multinational research effort with the goal to demonstrate intelligent vehicle systems and autonomous vehicles.

The technology behind the electronic tow bar consists of an active longitudinal and lateral vehicle control system, which links two or more trucks by purely electronic means. The heart of the system is made up of the on-board computers of the vehicles, which coordinate all data relevant to the surroundings and the vehicles themselves. The trucks are connected by a 2.4 GHz radio link for the constant real-time exchange of vehicle data. On the basis of the data from the leading vehicle, the computer in the trailing vehicle calculates the control commands, which it relays to the dual-circuit hydraulic steering system and to the electronically controlled brake system and drive train with an automatic transmission. The trailing vehicle reacts appropriately and instantaneously to the maneuvers of the leading truck, for example braking or acceleration. Two video cameras in the second truck fix their "gaze" on a special recognition pattern of infrared lamps on the rear of the first vehicle. These two cameras have different focal lengths; the change from the close-range to the far-range camera occurs at a separation of about ten meters. On the basis of the information supplied by the cameras, the processing unit calculates not only the distance between the trucks - changes in direction of the first vehicle are also registered in terms of a distortion of the pattern. Once this information is evaluated by the on-board computer of the trailing vehicle, an appropriate change in course is initiated.

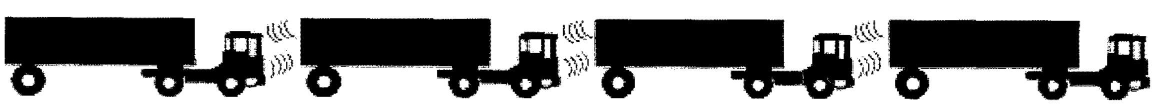

Figure 7: Truck Platooning using the Electronic Tow Bar

3.4.3 Automatic Emergency Braking

It is estimated that in 40% of rear end collisions involving trucks, the driver took no action to avoid the impact, which supports the needs for Active Rear-End Collision Avoidance Systems. This system is geared towards preventing rear end collisions and/or reducing the damages caused by the impact.

Two radar sensors estimate distance, direction and closing velocity of a preceding vehicle. In a situation of possible rear-end collision, an automatic emergency braking is initiated at the latest moment when no action on the part of the driver is possible but early enough to try to avoid impact.

4. Future Advances of these Systems and Technologies

4.1 Collision Warning, Forward-looking (CW):

Collision Warning systems using radar sensors are already available on the market although mass deployment is still years away. We believe that radar sensors have improved from the first generation that used 24 GHZ systems vs. the newer ones that uses 77 GHZ sensors.

An earlier version used at one point used infrared beam sensor but due to the superior performance of the radar in adverse weather and light conditions, future systems concentrated on the radar sensor only.

Less expensive versions with the infrared sensor are making their way in the passenger car area but we feel that their acceptance due to their reduced performance will not be high. So far, all major developments in the commercial vehicle area are centered on a radar sensor system.

The use of vision based systems is being investigated at this point but it is too early in the research stage to tell. A dual CMOS camera system for forward looking is in the prototype stage and the results are very promising. Although the system seems to be performing well at lower speeds and in congested areas, the sensor range will dictate the better system, specifically at higher speeds requiring active control as well as warning. The superior system will have a longer sensor range and better performance under various weather and light conditions. The camera system still requires a clean windshield area and direct light exposure still causes problems.

We believe at this point that the radar system will be the first system to be implemented on a large scale and we will see an integration or fusion of the radar and the camera. This fusion is needed to compensate for late detection in some cases due to the radar's narrow beam. That will reduce the percentage of false warnings and increase the acceptance of this safety device by the public. The future will be a dual sensor system (vision, microwave) with an average price of $500 /system within 5 years. The price of the system should come down with higher deployment and increased experience in the field will prove a favorable cost/benefit ratio. Some fleets have already experienced 50% reduction in collision with the earlier systems.

4.2 Blind Spot Detection and 360 CW:

At this time, the least expensive sensors are winning the battle. With the cost of video sensors continuing to go down, the cost/benefit ratio will swing favorably for advanced camera system that could be integrated in the side mirror. All agree that a better mirror system is needed to give more visibility to the driver but traditional thinking still includes the driver in the loop. We feel this system will become part of a full range solution for collision warning, forward, side, and rear.

While the predominant sensor in the front will most likely be a radar, we feel the side and rear sensor will be vision based (camera sensors). The benefit to the camera sensors is that they can detect multiple events or obstacles, basically provide input to more than one system at a time. Reducing the number of sensors on board the vehicle will be the focus as multiple systems try to compete for space and priority specifically in the 360 CW solution.

4.3 Lane Departure Warning system

These types of systems are highly desirable by fleets owners and drivers and with increased emphasis on battling accidents due to fatigue and drowsiness, a bright future is ahead.

We believe that system performance will have to improve in order to reduce false warnings and increase acceptance among drivers. At his time, cost is relatively high but will continue to go down as more units are deployed in the field. The system is compatible with other safety system and current research actually incorporates the system with other warning devices.(I.e. Adaptive Cruise Control, Vibro-Tactile Seating Systems,...).

4.4 Adaptive Cruise Control

Adaptive Cruise Control is the natural extension of the Collision Warning System that it is based on. Its future is dependent on the Collision Warning System acceptance and it will in time replace the CW system. The longitudinal control function of this system is a political issue at this point due to liability exposure of systems that interfere with driver functions.

The tracking performance of this system through curves needs to be improved before acceptability increases. The fusion of real time image processing system information with the radar will most likely be the future solution. Current developments already include video-input allowance and integration will follow in the next couple of years. The price target to the consumer in the next 5 years is expected to be around $750/system which should make it attractive to the fleets. In addition, efforts on the legislative side are being made to help trucks pay for safety systems' deployment through FET credits.

4.5 Rollover-Warning/Control

Rollover accidents are one of the top safety problems that are driving research in the safety systems area for trucks. At this time the system performance is marginal at best and a substantive field test is necessary before any thoughts to mass deployment are given. A couple of systems are being studied that involve sensing the tractor's dynamic behavior but not the trailer. There is a great support for this research from the Government agencies and the public but system performance at this time is the main obstacle. There is however some cooperative work between a trailer supplier and a truck OEM to design a system that includes the input from the trailer end. The future is very bright once the industry pursues a tractor trailer solution.

The warning system will eventually become a warning/control system. Users are more inclined to adopt a system that assists in the actuation as well as the warning task and with further sensor developments in the pipeline (3-dimensional gyroscope) system performance will improve dramatically.

4.6 Automatic Emergency Braking

This system will be the next feature in the evolution of Adaptive Cruise Control. It relies on existing ACC hardware but requires additional algorithms and Electronic Braking Systems (EBS) for the longitudinal control.

In five years an estimated 15% of new vehicles built will have brake-by-wire technology (EBS) which is a requirement for AEB. The system will be available in the next two years but its use will be dependent on the acceptance of collision warning systems and ACC.

We feel that EBS must not pose a cost penalty for operators over the existing ABS system to be acceptable. The liability roadblocks will be tackled in the years to come and once regulations are open to EBS the costs should begin decrease. Only then will fleet be more willing to use this system.

4.7 Electronic Tow Bar

Any type of autonomous driving is a decade away from any type of implementation unless you consider possible military applications. With time, a dedicated "trail" could help with the acceptance of platoons of trucks operating on the road. Until then, this type of research will serve as a laboratory for independent systems that could be "spun-off" along the way.

5. Conclusion

It is evident from Table 1 that all systems illustrated share some basic key components/core technologies, most importantly DSP's and mm-Radar. These components cost/performance relationships will continue to improve if we consider the trend in the semiconductor industry in our projection.

System	Core –Components, -Technologies, -Sub-Systems	Competitive Technologies
Collision Warning	Sensor: mm-Radar (Transm. & Receiver) ; DSP; Software	IR Laser-Radar
Blind Spot/360°CW	Sensor: mm-Radar (Transm. & Receiver) ; Software	CCD image/video
Lane Departure Warning	Sensor: CCD image/video; DSP; Software	IR Transm. & Receiver
Adaptive Cruise Control	Sensor: mm-Radar (Transm. & Receiver); DSP; Software	IR Laser-Radar
Rollover Warning/Control	Sensor: t.b.d. ; EBS; Software	
Autom. Emergency Braking	Sensor: mm-Radar (Transm. & Receiver.); DSP; Software	CCD image/video
Electronic Tow Bar	Sensor: IR CCD image/video; DSP; Software	

Table 1: Core -Components, -Technologies and -Sub-Systems