

Sensor Fusion as the Key in a Unified and Robust Commercial Vehicle Driver Assistance System

Brendan Chan and Ananda Pandey
Bendix Commercial Vehicle Systems LLC

ABSTRACT

Recently, the development of various driver assistance systems into today's vehicle have increased due to the availability of affordable advanced electronics. With this increase in electronic content on today's commercial vehicles, various opportunities for sensor fusion are opened up, primarily because the sensors are typically part of the ECU cluster, and always measuring either driver input, vehicle states and potentially the environment around the vehicle. Given the larger variance in vehicle mass and length for commercial vehicles, as opposed to passenger cars, sensor data integrity and robustness is important to assure that all the sensors are reporting the same information, so that safety-critical Driver Assistance Systems can intervene effectively and robustly. An example of a fusion system will be discussed, consisting of a forward looking camera sensor paired with a forward looking radar and other vehicle sensors to provide improvement in both the acquisition of the kinematic properties of the forward vehicle and the estimation of the host vehicle state, as well as improved vehicle control.

CITATION: Chan, B. and Pandey, A., "Sensor Fusion as the Key in a Unified and Robust Commercial Vehicle Driver Assistance System," *SAE Int. J. Commer. Veh.* 5(2):2012, doi:10.4271/2012-01-2012.

INTRODUCTION

For years, the passenger car industry has been developing concepts of data fusion in order to support advanced Driver Assistance Systems (DAS). As the development of DAS systems undergo a transformation from just serving as a comfort feature to functioning as preemptive safety systems, and electronic systems are becoming more readily available to modern vehicles, there are more concerns about the activation criteria. For the most part, an active safety system is meant to serve as a secondary safety system in a critical situation in the sense in which it is only supposed to intervene when there is a confirmed need to intervene. Currently, there are several functionalities that serve as the core of DAS, such as adaptive cruise, collision mitigation and lane departure warning. In commercial vehicles, the adoption of such systems can potentially reduce the insurance costs of the carriers.

For commercial vehicles, as mentioned, there are already several systems that are available such as forward collision mitigation systems (FCMS) and adaptive cruise control (ACC) [12, 13]. Most systems on the market currently provide the capability to first warn the driver, then slow down the vehicle either by applying the engine brake and/or the foundation brakes. In the most common cases, autonomous interventions are usually preceded by some form of visual or

auditory warning for the driver. The final results of the intervention provided by these technologies include, but are not limited to:

1. Warning the driver to take control of the vehicle if he/she is not attentive.
2. Assisting the driver to maintain control of the vehicle, especially during avoidance maneuvers.
3. Reducing the speed of the vehicle to either lessen the crash severity, or avoid the collision entirely.

Most of the FCMS available for commercial vehicles use one sensor, typically radar systems, as shown in Figure 1, to provide the adaptive cruise control/warning system with information on objects in front of it. Such systems, typically denoted as ACC systems, and usually require that the cruise is set and active for any active engine/braking intervention to occur.

However, over time, ACC systems on the market have evolved to include the Automated Emergency Braking (AEB) system. Contrary to the functionality of ACC systems, AEB systems typically do not require cruise control to be set or active to intervene. To ensure that road safety is improved by the AEB, the AEB system should never be needed until an emergency situation arises. In order to quantify of the overall safety impact of the AEBs, there exists a need to develop a

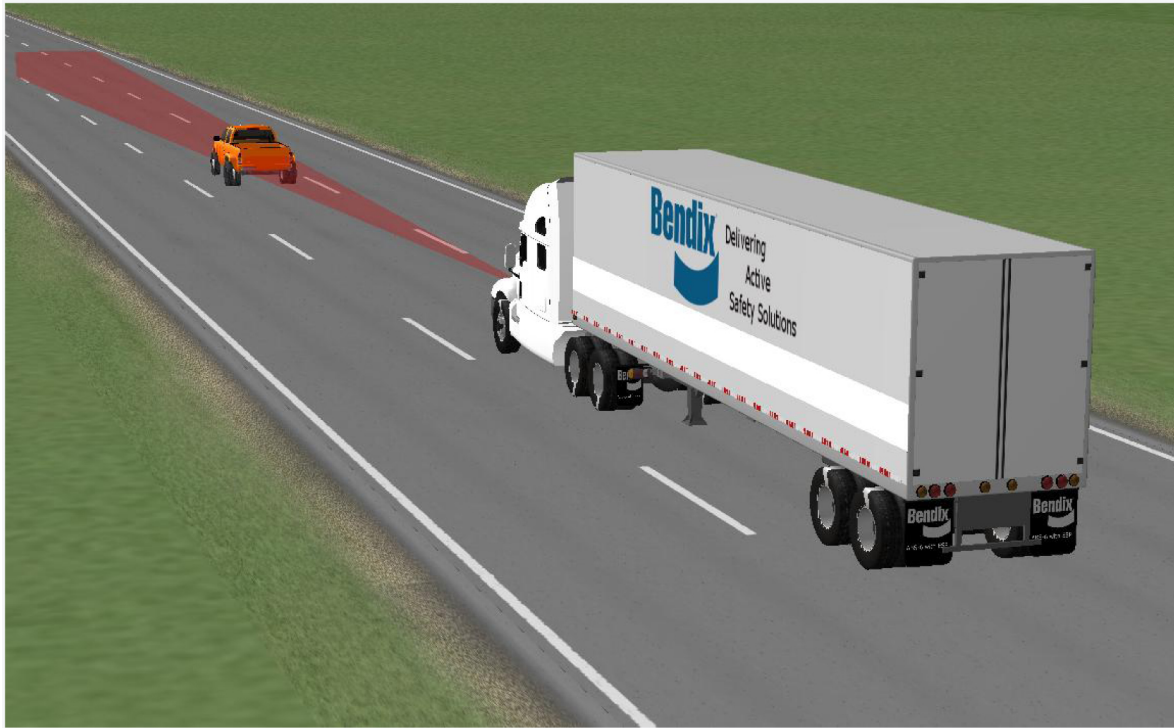


Figure 1. A tractor-trailer vehicle simulation model with a forward-looking radar in the front of the vehicle. The field of view of the radar is shown as the sector in red.

safety criteria that can provide an objective quantitative measures of safety. Time-to-collision (TTC) had been proven to be a good effective measure for rating the severity of collisions[15]. Given the distance $x(t)$ between two vehicles in as a function of time, t , the instantaneous speed between two vehicles can be approximated by the derivative of $x(t)$ with respect to time, and the time-to-collision $TTC(t)$ can be defined as:

$$TTC(t) = \frac{x(t)}{\dot{x}(t)} \quad (1)$$

However, contrary to popular belief, the availability of ACC or AEB on a vehicle does not necessarily mean that a collision may be avoided completely. Whilst most ACC systems are often designed to function as a comfort feature, most AEB systems are designed to be safety critical system. Hence, the braking strategy of each system may be potentially different. In all cases, the laws of physics still apply, and the momentum of the vehicle needs time to be dissipated via the foundation brakes. When you take a look at commercial vehicles and their applications, the vehicle mass may potentially change significantly depending on operation (garbage trucks and tankers) and combination length (single combination, doubles and triples). Braking too hard or too soon may cause the trailers to start drifting out of the lane, especially when the road surface is covered in snow and ice. One of the most effective interventions on vehicles involves providing either visual, auditory or tactile warnings to

drivers. The driver warning by most systems aim to induce distracted drivers to take control of the vehicles, especially during a situation where the traffic pattern suddenly experience a sudden change. With properly designed Human-Machine Interface (HMI), the driver could be alerted to respond to a potentially dangerous situation, and may avert a collision just because he/she has extra time to react, thus reducing the need for an autonomous intervention. The typical progression of events that can be expected in a collision mitigation situation is shown in Figure 2. In a collision mitigation event, it is normally observed that the systems on the market will warn the driver first, so that the driver will intervene to mitigate or avoid the collision event. After that, so form of emergency pre-braking is typically employed to assist the driver to apply brakes to the vehicle. Finally, if the driver has been unresponsive to the situation, the critical braking intervention is applied to the vehicle as a final resort.

In the unlikely case in which the driver is unable to respond in a timely manner to avoid collision, the FCMS may apply braking or engine retarder to slow the vehicle down. The Federal Motor Carrier Safety Administration (FMCSA) has conducted a rather extensive study [11] about the financial benefits of FCWS. According to the study, a rear-end crash for a commercial vehicle may incur numerous costs to the carrier. In addition to that, lane departure events may result in loss of control for the combination vehicle and accidents where both cargo and vehicle may be lost. Hence,

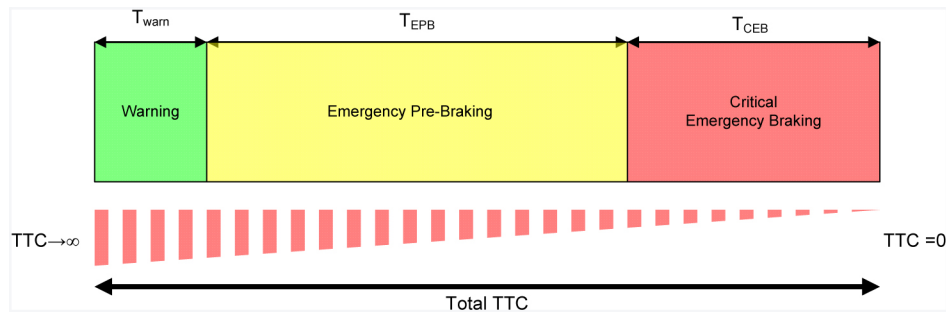


Figure 2. Typical collision mitigation strategy employed by most systems available on the market, with some form of warning first, and then an active braking intervention.

there are definitely benefits to having a multifaceted active safety system onboard a vehicle.

When the vehicle involved in the accident is moving high value cargo, the cost vs. benefits argument shift significantly towards the benefits. According to [11], the cost estimate for a high-value cargo rear end crash with fatality is \$1,103,721, compared to a Property Damage Only (PDO) rear end crash, which only has an estimated cost of \$ 170,150. Hence, even if the system only reduces the severity of the crash to a PDO crash, there are already significant financial benefits to be reaped. Hence, according to the FMCSA, various collision mitigation systems can be installed by Original Equipment Manufacturers (OEMs) when the vehicles are manufactured and costs approximately \$2,500 over the costs of anti-lock braking systems and stability control systems, but the price may potentially vary depending on the number of units acquired. Even with such costs, it is noted that the benefits of such systems outweigh the costs.

FORWARD COLLISION SENSORS



Figure 3. Some of the radar-based FCMS that are available on the market for commercial vehicles include the Bendix Wingman System (a) [11] and the Wabco OnGuard System (b) [12]. Typically these systems are mounted on the front of the commercial vehicle.

There are various combinations of different sensors in the different FCMS systems that are deployed in the market today. Two of the most widely available radar-based FCMS systems is shown in Figure 3. In most cases, the combination of sensors will have to be balanced between cost and performance. It is expected that with modern technological

advances, the systems are expected to be more affordable to fleet owners and independent operators.

FORWARD COLLISION SENSORS : RADAR

There are several different types of radar used in active safety systems today. The main principle of radar systems are based on Doppler shift of frequencies as objects move towards each other. The ratio of the Doppler frequency shift can be approximated using equation (2). When the object is moving away from the radar, the ratio will decrease but when the object moves closer to the source, the ratio will increase [22].

$$\frac{f'}{f} \approx 1 - \frac{2u}{c_{air}} \quad \text{when} \quad \frac{u}{c_{air}} \ll 1$$

(2)

Where:

f' = Frequency of reflected wave
 f = Frequency of transmitted wave
 u = Speed of moving object
 c_{air} = Speed of radar wave in air

There are a variety of radar technologies and sensors available for usage in an automotive application. Considering the currently available devices on the market, there are five main types of radar technologies used for automotive collision mitigation, namely; Frequency Modulated Continuous Wave (FMCW), Switched Beam Pulse Doppler, Switched Beam FMCW, Simultaneous Beam FMCW, and Monopulse-FSK.

All the different types of Radar shown in Table 1 have different performance characteristics for stationary and moving objects.

From the information shown in Table 2, we can observe that there are pros and cons to various types of radars out in the market. As with any other product, there is a need to perform a trade-off between cost and performance.

Table 1. Features of the different types of RADAR used for Automotive applications [16].

Radar Type	Features
Frequency Modulated Continuous Wave	- Scans Narrow Beam Over Wide FOV. - FMCW down converts wide RF bandwidth to narrow video bandwidth. - Multiple FMCW slopes used to measure range and range rate. - Beam position with amplitude interpolation used to measure angle. - Best angle discrimination, good range and range rate discrimination.
Switched Beam Pulse Doppler	- Three sequential beams to cover limited FOV. - Steps through (wide) range gates sequentially to reduce processing bandwidth. - Range rate with amplitude interpolation used to measure range. - Doppler frequency shift used to measure range rate. - Sequential lobing (amplitude comparison) used to measure angle. - Coarse angle, range and range rate discrimination.
Switched Beam FMCW	- Three sequential beams to cover limited FOV. - FMCW down converts wide RF bandwidth to narrow video bandwidth. - Multiple FMCW slopes used to measure range and range rate. - Sequential lobing (amplitude comparison) used to measure angle. - Coarse angle discrimination, good range and range rate discrimination. - Range rate discrimination better than scanned FMCW.
Simultaneous Beam FMCW	- Similar to switched beam FMCW except: - Three simultaneous beams cover limited FOV. - Long dwell times provide fine range rate discrimination.
Monopulse-FSK	- Single, wide transmit beam to cover wide FOV. - Two narrowband dwells at different RF frequencies used to measure range. - Doppler frequency shift used to measure range rate. - Dual sum & difference antenna-receive channels used to measure angle. - Long dwell times provide fine range rate discrimination. - No discrimination in range or range rate.

FORWARD COLLISION SENSORS : OTHER SENSORS

In addition to radars, there are other types of sensors that are employed by modern vehicle collision mitigation systems. One of the alternative sensor to radar technology is Light Detection and Ranging (LIDAR), which uses the same basic principle as radar. The lidar instrument transmits light out to a target. The transmitted light interacts with and is changed by the target [17]. Some of this light is reflected / scattered back to the instrument where it is analyzed. The change in the properties of the light enables some property of the target to be determined. The time for the light to travel out to the target and back to the lidar is used to determine the range to the target.

Compared to radar sensors, lidar sensors typically do not do direct measurement of both range and range-rate parameters simultaneously. Lidar, because of the fact that it is based on ranging technology, only directly measures range, so velocity and acceleration has to be extrapolated and estimated. However, a lot of the shortcomings in lidar technology can be offset by advanced software designs. Some of the features available on today's lidar sensors include compact designs, wide FOV with electronic switched beam approach, multitarget tracking and automated electronic

detection and compensation of sensor mechanical misalignments [14].



Figure 4. A lidar unit offered in the market as a sensor for active safety systems for passenger cars [18].

In addition to radar, another very popular sensor used for DAS is the camera. Forward looking cameras often serve as the primary sensors for lane departure warning systems and also collision mitigation systems. For lane departure systems, the camera, typically located behind the windshield is