Heads-Up-Display Collision Warning and Traffic Monitoring System

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Abstract

This paper will present a radar-based Collision Warning and Avoidance System (CWAS). The objective of this study is to acquire an accurate and detailed estimation of the traffic situation in front of a vehicle using a laser radar sensor. Provided with the sensory information, the system will be able to track multiple vehicles using Fuzzy Logic clustering and Kalman filtering techniques. Essential traffic monitoring and warning information will be displayed on a Heads-Up-Display. The range to detect vehicles will be up to 100 meters. A throttle relaxer is implemented as the actuator for collision avoidance.

The laser radar collision warning and traffic monitoring system is part of the *"Artificial Intelligence based Heads-Up Display as Driver's Aid System"* (AHDAS) This work was conducted under U.S. ARMY Tank-automotive & Armaments Command (TACOM) National Automotive Center (NAC) Contract No. DAAE07-96-C-X152 in a collaboration between TACOM, Oakland University and Industry. The objective is to develop a driver's aid system for military vehicles that includes a traffic monitoring and collision avoidance system. The system is implemented on a HMMWV (High Mobility Multi-purpose Wheeled Vehicle).

Keywords: Heads Up Display, Radar Traffic Monitoring, Collision Warning, Object Avoidance.

1. Introduction

In the past decade, the automotive industry has focused its attention more and more on semi-active and active safety measures. By providing vital information and assisting the human driver in driving his/her automobile safely, the safety devices work to prevent an accident rather than to diminish material, economical or emotional damage. The many topics, discussed in magazines and journals on advanced automotive safety devices emphasize the thrust of automotive related research institutes all over the world, for the effort to enhance automotive safety. Some of the terms are *Intelligent Highway Systems, Sensor Fusion, Air bag, Active Suspension, Driving Stability, Smart Windshield Wipers, Intelligent Cruise Control,* and *Collision Warning* and *Avoidance.*

Accidents that could be avoided with a forward-looking CWAS are usually termed *rear-end accidents*. The driver in fault hits a vehicle ahead from the back. Most of the rear-end accidents are caused by a driver not paying attention to the traffic situation. In vehicles equipped with CWAS, the driver could be warned for potential danger and pay attention to the road and the situation to avoid an accident.

The US Army also has applications for CWAS. Every year the US Army fleet suffers a 25 million dollar loss in damages and medical costs due to wheeled vehicle accidents worldwide. Rear end

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accidents account for 40% of all army crashes and statistics show that a forward looking CWAS can avoid 23%-31% of this type of collisions [3].

The conventional laser radar based CWAS generally monitors one front vehicle, eventhough it can cover several areas and vehicles in front of the vehicle. Laser radar can be used, is more robust than a millimeter wave radar considering interference from the environment [2]. Research on traffic monitoring using laser-radar has been done before in [4] by using Kalman filtering to track multiple vehicles. Actuation however was not part of that research and the system was therefore passive. Monitoring the entire traffic situation in front rather than only the vehicle in front, significantly increases the information obtained for improving safety. By processing radar information to track up to five vehicles in front, great benefit is gained in the performance of the CWAS. This increase in reliability allows us to effectively control the vehicle in case of danger. Concerning detection range, it is stated that 100 meters is ideal to obtain relevant information [8].

A dual objective will be the focus for the Collision Warning and Avoidance System. At any instance in time, this system will try to avoid any collision with any object. Beyond that, in the case of a collsion, it will try to minimize crash impact by early driver warning and automatic actuation.

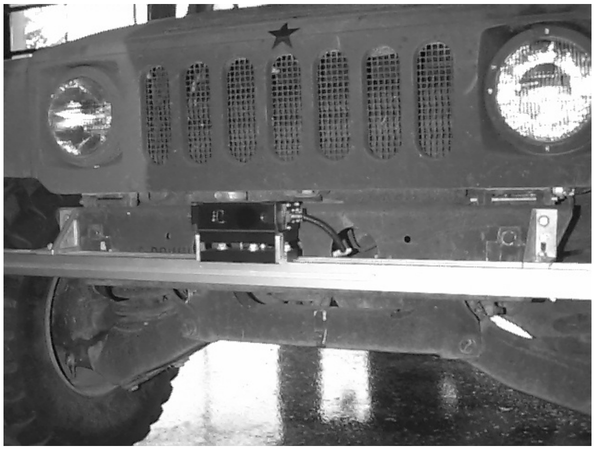


Figure 1 Laser radar sensor mounted on the front bumper of a US Army HMMWV

Here we present a real-time system that has proven to be reliable and to have a minimum of false alarms. Great attention is also given to the usability and convenience for the driver. The display is Heads-Up and icon-based and the allerts are augmented by voice and sound.

CWAS will typically contain three levels of functionality. They are perception, decision making and actuation. In the following these three tasks will be discussed in more detail. The paper will be concluded with simulation and experimental results.

2. Scope of the Problem

Figure 1 shows the radar device mounted on the front of a HMMWV. Three main stages can be recognized for the CWAS. They are

Sensor The laser radar is a stand-alone device, that sends its data in a continuous stream to the processor. The frames contain the distances measured per radar, statistical information about the data and temperatures.

Decision The decision part consists of a Kalman filter with adaptive tuning gain. Figure 4 shows the flow diagram of the algorithm. The algorithm estimates and predicts surrounding vehicle positions, and eliminates fictitious predictions. The concept will be explained in Section 4.

Actuation The output of the decision part has information on the direction and distance of headway traffic. In a simple algorithm this information can be translated into three warning levels. The highest alert of warning will activate a throttle relaxer that will slow down the vehicle, overruling the driver's intention. Section 5 will explain this part.

The next sections will discuss these tasks in more detail.

3. Laser Radar Sensor

A commercial laser radar sensor was purchased and mounted on the front of the vehicle, as shown in Figure 1. The laser radar emits three beams of near-infrared light in different directions and uses the time-of-flight method to calculate the distance to a vehicle in front for each of the three beams.

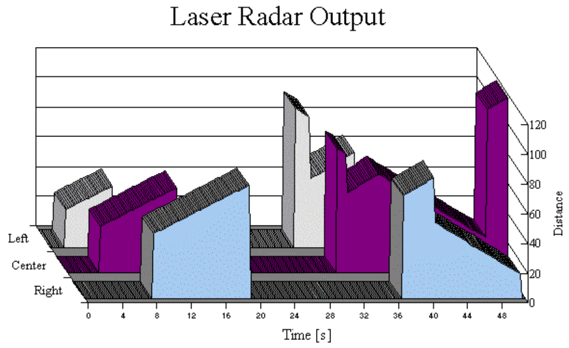
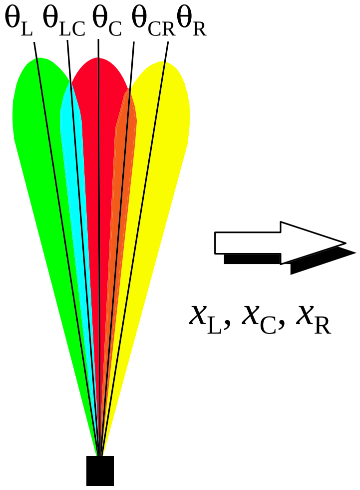


Figure 2 Typical readout of the Laser Radar

A finite time experiment with the system will return raw laser sensor data as represented in Figure 2. For this particular experiment, in the first twenty seconds, an object moves from the left to the right in front of the vehicle, increasing its distance. At approximately 30 seconds, a vehicle far ahead comes in sight, just before another object, much closer, enters the beam and therefore shadows the farther object. In the end of the experiment, however, the center beam shows shortly a pick-up of the farthest object. A requirement for the laser radar is that the object to be recognized should have reflective material. If that is so, the device is reliable, however, if the object is dirty or not smooth, the laser can show misses in the experiments.



If $|x_i-x_j|<T$ or $|x_i|<T$ then 0 else 1

x_L	x_C	x_R	x_L-x_C	x_C-x_R	x_R-x_L	^1x_k	^2x_k	^3x_k
0	0	0	-	-	-			
0	0	1	-	-	-	$[x_R\ \theta_R]'$		
0	1	0	-	-	-	$[x_C\ \theta_C]'$		
0	1	1	-	0	-	$[(x_C+x_R)/2\ \theta_C]'$		
			-	1	-	$[x_C\ \theta_C]'$	$[x_R\ \theta_R]'$	
1	0	0	-	-	-	$[x_L\ \theta_L]'$		
1	0	1	-	-	0	$[(x_L+x_R)/2\ \theta_{LR}]'$		
			-	-	1	$[x_L\ \theta_L]'$	$[x_R\ \theta_R]'$	
1	1	0	0	-	-	$[(x_L+x_C)/2\ \theta_{LC}]'$		
			1	-	-	$[x_L\ \theta_L]'$	$[x_C\ \theta_C]'$	
1	1	1	0	0	0	$[(x_L+x_C+x_R)/3\ \theta_C]'$		
			0	0	1	$[(x_L+x_C+x_R)/3\ \theta_C]'$		
			0	1	0	$[(x_L+x_C+x_R)/3\ \theta_C]'$		
			0	1	1	$[(x_L+x_C)/2\ \theta_{LC}]'$	$[x_R\ \theta_R]'$	
			1	0	0	$[(x_L+x_C+x_R)/3\ \theta_C]'$		
			1	0	1	$[(x_C+x_R)/2\ \theta_C]'$	$[x_L\ \theta_L]'$	
			1	1	0	$[x_L\ \theta_L]'$	$[x_C\ \theta_C]'$	$[x_R\ \theta_R]'$
			1	1	1	$[x_L\ \theta_L]'$	$[x_C\ \theta_C]'$	$[x_R\ \theta_R]'$

$^1x_k \sim {}^{Nv}x_k$

Figure 3 The three beams of the laser radar and the decision table to decide for the locations of the object s in case of multiple beam readout.

4. Decision

In this section we will take a closer look at the estimation and prediction of frontal traffic and at the estimation of the object locations in real time. Generally, the objects will be the vehicles as part of the traffic in front of the test vehicle.

This functionality is integrated using a Kalman filter, where the update gain *R* for measurements is chosen accordingly. The algorithm is graphically represented in the diagram in Figure 4. The signal processing to detect and track vehicles is performed in four stages, using a first order model of car dynamics:

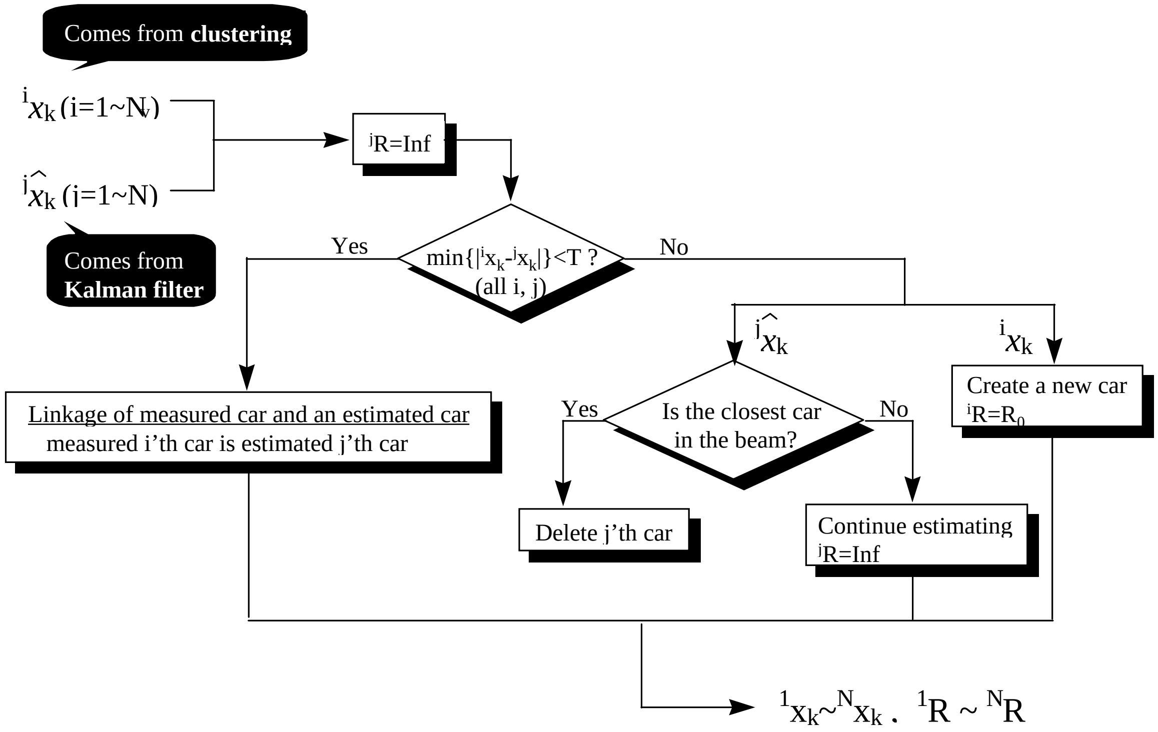


Figure 4 The Aglorithm Flow Chart where measured and predicted object locations are matched, verified and administrated.

These four steps will be highlighted hereafter.

1. New measurement data from the radar is extracted from the data frames. The distance information can be derived in a straightforward manner, since it is the value that the sensor device returns. The direction information however is not as trivial. From Figure 3 it can be seen that with the overlaps of the beams, three consecutive pie-shaped areas can be distinguished. Hence, the directional resolution is very low, and could be improved by using two triple-beam laser-radars [1].

Symbol	Meaning
${}^{i}X_{k}$	State of system dynamics of i'th vehicle at time *k* relative to our own vehicle
${}^{i}Z_{k}$	Distance measurement with laser radar
${}^{i}W_{k}$	System noise caused by drivers intensions
${}^{i}V_{k}$	Measurement noise introduced by inaccuracy of laser radar
A	Vehicle dynamics matrix
H	Measurement matrix
${}^{i}P_{k}$	Covariance in ${}^{i}X_{k}$
${}^{i}Q_{k}$	Covariance in ${}^{i}W_{k}$
${}^{i}R_{k}$	Covariance in ${}^{i}V_{k}$
μ	mean value

Table 1 Nomenclature : names of the variables and their meaning.

To retrieve the direction information from the sensor, a decision table is used that is given in Figure 3. From three return values from the sensor, representing distance, the direction can be derived by averaging equal values in directional sense. For example, take the 4th and 5th line in the table in Figure 3. Both the center and the right beam detect an object. If their values for distance is essentially different[1], two objects are detected with the direction that equals the center of the two beams. If, however, the values are equal, the average distance is calculated and the middle of the overlap of the center and right beam is taken as the direction of the one object that is identified.

2. Comparison of the estimated object locations with the predictions from the previous time step, will conclude which measurement fits which prediction. These predictions will be updated with the measurement data. The remaining predictions will be verified to make sure that they are farther away from the radar than another object in the same beam, and to be only a predicted object for a limited amount of time[2], otherwise, the object will be deleted from the object list. If there is a measurement from the laser radar which could not be matched with a predicted object, a new object will be created and stored in the object list of the system. Its belonging distance set to the measured *R*.

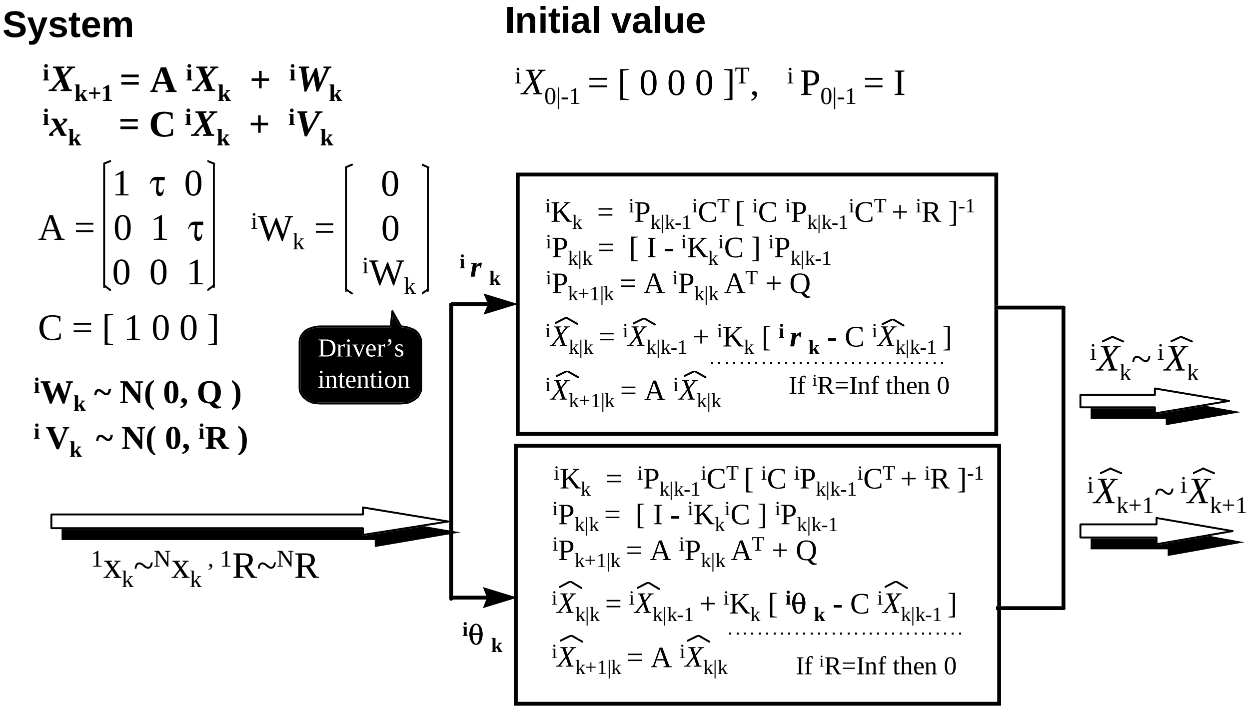


Figure 5 The recursive Kalman filter that is used to predict estimates for the distance and angle of the objects

3. Deleting or creating objects in the object base is necessary for all objects and measurements that could not be matched as one. The basic assumption at this comparison stage is that positions of vehicles don't change suddenly but gradually. If the difference between certain time-update and measurement-update is within a predefined treshold, this is considered to be one and the same vehicle. Then the measurement value of the relative distance is taken. If there is a time-update and no corresponding measurement up-date, the time-update is taken as the relative distance. There's one exception for this last case: if the time-update is the most nearby vehicle then it is disregarded, because there should be a measurement-update, since there's no obstacle to obstruct measurement.

4. The new positions of the objects in the object state base at time *k* are estimated for time *k+1*. Figure 5 shows the equations for updating the current estimates for time *k+1*.

Table 1 explains the meaning of the various variables. The essence of the predictor is the update gain *R*. The topmost equation in Figure 5 shows that the recursive gain $^{i}K_k$ becomes 0, when

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[1] This range is an essential parameter of the system, incorporating measurement noise and prediction errors.

[2] The so called time-of-life of a predicted object, without matching of an actual measurement is also an important parameter. The object state base could grow if the rate of misfires is larger than the rate of deleting old predictions.

$R = \infty$. In that case, from the 4th equation we see that the states of object i (denoted by ${}^{i}X_k$) will remain the same for the next sample step. If $R \neq \infty$, then the new prediction for the states of object i will be corrected with the measurement data.

5. Actuation and the Warning system

If distance, relative speed and direction of surrounding obstacles are known, then a *Time to Collision* can be derived which will be the cue for the warning system. This section will explain how the information from the Kalman Filter in the previous section will be used to signal the driver and in worst case, actuate the throttle relaxer.

Some variables and parameters that will be used are defined as follows.

t_c	Time to collision
t_b	Time to brake
t_r	Driver's reaction time
r_k	Distance between our vehicle and front vehicle
v_r	Relative velocity between our vehicle and front vehicle
D_{min}	Minimum needed deceleration to prevent collision
D_{max}	Maximal deceleration from brakes

For each object in the traffic monitor we can determine a Collision Warning indicator. The first-order estimate of time to collision is calculated from the distance and relative speed of the object and is given by

$$t_c = \frac{r_k}{v_r}$$

If t_r is the reaction time of the driver, then the time to collision can be formulated as $t_c = t_b + t_r$ which leaves less deceleration time t_b to avoid a collision. The minimum needed deceleration can be formulated as the relative speed over the remaining time to brake, or in formula

$$D_{\min} = \frac{v_r}{t_c - t_r}$$

The ratio of D_{min} over the maximum braking decelaration, D_{max}, of the vehicle can be used as Collision Warning Indicator (CWI).

$$CWI = \frac{D_{\min}}{D_{\max}}$$

The CWI will be partitioned into three intervals, each of which belongs to a particular warning level. The three levels from low alarm to high alarm respectively are “attention”, “alert” and “warning”. At this point the warning system has a binary behaviour, i.e. it will be in no state or in either of the three mentioned above.

As soon as the system state “warning” becomes active, a throttle relaxer is actuated, so that the vehicle will slow down and besides the visual and audio signals, the driver will be warned by the vehicle slowing down.

6. Simulation and Experimental results

Experimental results have been recorded onto video and will be shown during the presentation at the conference. The study, which has a strong emphasis on the implementation, can best be validated by a demonstration from the driver’s viewpoint behind the wheel during an actual testdrive.

7. Conclusions

One practical problem with the laser radar is the dirt on the screen of the sensor housing[9]. The dirt causes significant decrease of sight and performance of the system. A newer version of this particular sensor is equipped with a miniature windshield wiper.

As mentioned in Section 4, the directional resolution of the sensor is very limited. Various researchers have tried to improve on this, using two laser radar devices with small overlap [4], [1]

The research that was presented in this paper is done in a field that entertains many in acedemic and automotive research labs. A strong thrust can be noticed towards intelligent vehicle maneuvering and intelligent collision avoidance [5] [6]. Higher level control and decision algorithms will make vehicles even safer in future automotive products [7].

From the many test runs, it was experienced that it is very important to have the output that interfaces with the human driver, to be compatible to human perception. The choice of visual and audio cues becomes an important performance issue with this human-in-the-loop system.

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References

[1] Ka C. Cheok, S. Nishiza w a, W. J. Young, and W. Zhao. *Traffic monitor using two multiple-beam laser radars*. In Proceedings of the IFIP, 1997.

[2] M. Hischke. *Collision warning radar interference*. In Annual Meeting of ITS America , Houston, USA, 1996. 6

[3] Management Analysis Inc. US army wheeled vehicle accidents : Statistics and strategy. Technical report, US Army , Alabama, 1995.

[4] S. Kawashima, K. Watanabe, and K. Kobayashi. *Traffic monitoring by Kalman Filtering of laser radar signals*. In Proceedings of the IFAC World Congress , San Fransisco, 1996.

[5] C. A. Mullins, R. W. Schumacher, J. W. Weber, and C. D. Wright. *Integrated collision avoidance vehicle*.

[6] A. Najmi, A. Mahrane, D. Esteve, G. Vialaret, and J. J. Simonne. Pulsed lidar for obstacle detection in automotive Field : The measurement of reflectance range data in scene analysis. Sensors and Actuators , pages 497-500, 1995.

[7] Sadayuki Tsugawa. *Vision-based vehicles in japan: Machine vision systems and driving control systems*. IEEE Transactions on Industrial Electronics , Vol 41 No 4, pages 398-405, August 1994.

[8] T. Wilson, W. Butler, D. McGehee, and T. Dingus. *IVHS countermeasures for rear end collisions, driver warning systems performance guidelines*. In Annual Meeting of ITS America , Houston, USA, 1996.

[9] T. Yasuma, A. Gonmori, S. Matumori, and J. Nishino. Performance and function of the collision avoidance warning system with a small sized laser radar.