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Designing an integrated driver assistance system using image sensors

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Abstract Road accidents cause a great loss to human lives and assets. Most of the accidents occur due to human errors, such as bad awareness, distraction, drowsiness, low training, and fatigue. Advanced driver assistance system (ADAS) can reduce the human errors by keeping an eye on the driving environment and warning a driver to the upcoming danger. However, these systems come only with modern luxury cars because of their high cost and complexity due to several sensors employed. Therefore, camera-based ADAS are becoming an option due to their lower cost, higher availability, numerous applications and ability to combine with other systems. Targeting at designing a camera-based ADAS, we have conducted an ethnographic study of drivers to know what information about the driving environment would be useful in preventing accidents. It turned out that information on speed, distance, relative position, direction, and size and type of the nearby objects would be useful and enough for implementing most of the ADAS functions. Several camera-based techniques are available for capturing the required information. We propose a novel design of an integrated camera-based ADAS that puts technologies—such as five ordinary CMOS image sensors, a digital image processor, and a thin display—into a smart system to offer a dozen advanced driver assistance functions. A basic prototype is also implemented using MATLAB. Our design and the prototype testify that all the required technologies are now available for implementing a full-fledged camera-based ADAS.

Keywords Image sensors · Video-based analysis · Advanced driver assistance system · Context-awareness · Road safety · Smart cars · Intelligent transportation system

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Introduction

Annually, road accidents cause about 1.2 million deaths, over 50 million injuries, and global economic cost of over US$ 518 billion (Peden et al. 2004). About 90% of the accidents happen due to the driver behavior (Treat et al. 1977), such as bad awareness of driving environment, low training, distraction, work over-load or under-load, and low physical or physiological conditions. An advanced driver assistance system (ADAS) can play role in improving driver awareness and hence performance by providing relevant information as and when needed. ADAS augment safe and smooth driving by actively monitoring the driving environment and producing a warning or taking over the control in highly dangerous situations. Most of the existing systems focus on only single useful service, such as parking assistance, forward collision warning, lane departure warning, adaptive cruise control, and driver drowsiness detection. Recently, many researchers have proposed integrated ADAS that combines multiple services into a single system in an efficient and cost effective way.

Vision-based ADAS use cameras to provide multiple services for driver assistance. They are becoming popular because of their low-cost and independence from infrastructure outside the vehicle. For example, an intelligent and integrated ADAS (Kim et al. 2008) uses only two cameras and eight sonars, and others make use of only cameras (Fletcher et al. 2003; Trivedi et al. 2007; Nedevschi et al. 2007; Andrade et al. 2004; Finnefrock et al. 2005; Handmann et al. 2000). They present information through an in-vehicle display. For better situation awareness for drivers, different systems have been introduced to display the surrounding environment of the vehicle (Ehlgen et al. 2007; Cheng et al. 2007; Rakotonirainy et al. 2008; Pugh 2008; Liu et al. 2008b). These recent developments show that the future lies in vision-based integrated ADAS. Advantages of vision based integrated systems include lower cost; improved performance; innovative features support; integrated with new as well as old vehicles having no support for infrastructure; and easy to develop, install and maintain. That is why they are getting much attention from researchers in academia and automotive industry. Current research mainly focuses on introducing traditional driver assistance systems based on camera, and then combining these individual systems into an integrated ADAS.

However, despite much advancement in ADAS, the issues of information-overload for drivers have been ignored, and a little attention is given to the interface and interaction design for vision-based ADAS. It is important to note that a driver can pay only a little attention to the displayed information while driving. Therefore, the system should provide only relevant information, in a distraction-free way, as and when needed. Aiming at development of vision-based ADAS, we carried out an ethnographic study of how people drove their vehicles, observed their activities while they drove, engaged them in discussions, and used questionnaires to get feedback. We were particularly interested in finding answers to the following questions:

1. What information about the surroundings should be provided to drivers for better situation awareness?
2. How should this information be presented to drivers in a distraction-free way?
3. How should drivers interact with the proposed system?

The results of this ethnographic study, which are reported in (Akhlaq 2010), have guided us towards the development of a novel design of camera-based ADAS. However, camera-based automotive applications are still in development phase and will take another few years to gain reliability. A timeline provided by Mobileye (Mobileye Future Launches 2010), one of the vision industry leaders, says that all vision-based ADAS will be available only in 2013. However, we suggest that all the required technology is now available for implementing a full-fledged vision-based ADAS.

The paper is organized as follows. In section "Related work", we present a survey of different camera-based ADAS projects. In section "Technologies", we summarize the available camera-based technologies for measuring speed, distance, relative position, direction of movement, and size and type of on-road objects. In section "The system design", we provide an architecture and design of the proposed ADAS system along with a basic prototype. In section "Strengths and weaknesses", we identify the strong points and possible flaws associated with the proposed design. Finally, we conclude our work and suggest some future research in the last section.

Related work

Road safety is an important and well-researched issue. This area is so vital that many governmental bodies in developed countries have issued a set of requirements for systems regarding road-safety. For the last many decades, a large number of projects or studies have been undertaken under the flag of road-safety, intelligent transportation, IVIS (in-vehicle information system) and DSS (driver support systems). There are hundreds of active projects in industry, universities, and research centers. Most of these projects concentrate on single aspect of the system, such as LDW (lane departure warning), while others consider only a few aspects. In this section, we classify and describe some representative studies or projects.

Advanced driver assistance systems (ADAS)

ADAS, also known as driver support systems (DSS), support drivers in driving a vehicle safely and smoothly. They provide drivers with an extra ease, decreased workload, and more focus on the road, and hence reduce the risk of accidents. Examples of such systems include adaptive cruise control (ACC), forward collision warning (FCW), lane departure warning (LDW), adaptive light control (ALC), traffic Sign recognition (TSR), blind spot detection (BSD), driver drowsiness detection (DDD), in-vehicle navigation system, intelligent speed adaptation (ISA), vehicle-to-vehicle (V2V) communication, on-road object recognition, and night vision etc. (Kim et al. 2008).

Intelligent vehicle initiative—IVI (Nookala and Estochen 2002) and intelligent car initiative project—i2010 (Reding 2006) are the two famous examples of large projects covering many of these features. US Department of Transportation (1997–2005) funded the intelligent vehicle initiative (IVI), which aimed at preventing driver distraction, introduction of crash avoidance systems, and studying the effects of in-vehicle technologies on driver performance. European

Commission is funding the intelligent car initiative (i2010) project, which aims to encourage smart, safe and green system for transportation. It also promotes cooperative research in intelligent vehicle systems and assists in adopting research results. Under this initiative, many sub-projects are also funded such as AWAKE, AIDE, PReVENT and eSafety.

V2V communication in vehicular ad hoc network (VANET) has emerged as an important research area where on-road vehicles establish an ad-hoc wireless network to communicate with each other. These vehicles can automatically exchange anonymous information on traffic, route, safety etc with nearby vehicles at Euclidian distance of up to 1 km. A vehicle can act as a router in order to forward this information to other vehicles at a greater distance. To facilitate V2V communication, we need either to search objects of interest on a road within a certain distance or range (known as range search) or to discover K nearest neighbors (KNN) on the route. Several protocols have been proposed for VANETS, including the protocols for range search (Xuan et al. 2008a, 2011a,b), algorithms for KNN (Xuan et al. 2008b; Zhao et al. 2010), techniques for event sharing in VANET using geographic vectors and maps (Delot et al. 2011), methods for robust video communication in an urban emergency (Qadri et al. 2010), and simulators in order to evaluate the performance of routing protocols for VANET (Spaho et al. 2010).

Using V2V communication, we can implement several ADAS functions including ACC, BSD, and FCW etc. However, the main problem with V2V communication is that it heavily depends on infrastructure in and out of the vehicle that is very costly and not yet widely available. Therefore, most of the current implementations of ADAS functions use common technologies such as radar, sonar, lidar, GPS, or video-based analysis.

In-vehicle information systems (IVIS)

IVIS, also known as driver information systems (DIS), combine many systems, such as communication, navigation, entertainment, and climate control, into a single integrated system. They use LCD panel mounted on dashboard, a controller knob, and optionally voice recognition. IVIS are available in almost all the latest luxury vehicles.

US Department of Transportation, Federal Highway Administration in 1997, sponsored one of the earliest researches in this area. The goal of their in-vehicle information systems (IVIS) project (Spelt et al. 1997) was to develop a fully integrated IVIS that would safely manage highway and vehicle information, and provide integrated interface to the devices in the driving environment. The implementation was done on personal computers connected via Ethernet LAN. However, it came up with useful results. Similarly, HASTE (Santos et al. 2005) is a recent EU funded project that provides guidelines and tests the fitness of three possible environments (lab, simulator and vehicle) for studying the effects of IVIS on driving performance.

An IVIS can also make use of guidance and traffic information produced by the systems that are managed by city administration in the developed countries, for example, California Advanced Driver Information System—CADIS (Raghavan et al. 1992).

Warning systems

Recently, a number of in-vehicle systems have been developed that either alert the driver of the forthcoming danger or try to improve his behavior. Such systems are a sub-set of IVIS/ADAS because they handle only one or few features. In this section, we will briefly survey some of the prominent warning systems.

Night vision systems (Bergmeier 2008) use head-up display (HUD) to mark an object which is outside the field of vision of a driver. The mark on HUD follows the object until the point of danger is passed. A driver can easily know about the speed, direction and distance of the object. The next generation systems will also be able to recognize objects actively.

Dynamic speedometer (Kumar and Kim 2005) addresses the problem of over-speeding. It actively considers current speed limit information and redraws a dynamic speedometer on dashboard display in red. Other similar projects include speed monitoring awareness and radar trailer—SMART (Perrillo 1997), which displays the vehicle speed and the current speed limit, and Behavior-based safety—BBS (Knipling 2000) which displays the driver performance regarding speed.

The road-surface monitoring systems detect and display the surface condition of the road ahead. This is relatively new area of research in ADAS. A recent project, Pothole Patrol—P^2 (Eriksson et al. 2008) uses GPS and other sources to report path-holes on the route. Other examples include CarTel (Hull et al. 2006) and TrafficSense (Mohan et al. 2008) by Microsoft Research.

Safe speed and safe distance—SASPENCE (Adell et al. 2008) aims at avoiding accidents due to speed and distance problems. This project was carried out in Sweden and Spain in the year 2004. It suggests visual, auditory and haptic feedbacks, and provides alternatives to develop a DSS for safe speed and safe distance. Similarly, Green Light for Life (Lotan and Toledo 2005) uses an in-vehicle data recorder (IVDR) system to promote safe driving in young drivers. It uses messages, reports and an in-vehicle display unit to provide feedback to the young drivers.

Monitoring the driver vigilance or alertness is another important thing for road safety. A recent prototype system for monitoring driver vigilance (Bergasa et al. 2006) uses computer vision (IR illuminator and software implementations) to find level of vigilance. Automotive industry uses some other methods for monitoring driver vigilance. For example, Toyota uses steering wheel sensors and a pulse sensor (Kircher et al. 2002), Mitsubishi uses steering wheel sensors and measures of vehicle behavior (Kircher et al. 2002), Daimler Chrysler uses vehicle speed, steering angle, and vehicle position using a camera (Wilcox 1999), and IBM's smart dashboard analyzes speech for signs of drowsiness (Kanevsky 2008).

In-vehicle signing systems (IVSS) may read the road signs and display them inside the vehicle for driver attention. A recent example of such systems is the one prototyped by National Information and Communications Technology Australia (NICTA) and Australian National University (Wang et al. 2006). The IVSS may possibly use one of the following three techniques: image-processing or computer-vision (Wang et al. 2006), digital road-data (Sato and Makanae 2006), and DSRC—dedicated short range communications (Oki et al. 2003).

Safe Tunnel project (Vashitz et al. 2008) simulates tunnel driving and recommends the uses highly informative display to inform drivers of the incidents. A highly informative display might increase the threat of distraction but it might significantly improve safety.

Some recent warning systems use existing infrastructure, such as GSM, GPS, and sensors deployed in the road, cars or the networks. Examples include NOTICE (Abuelela et al. 2008) that proposes architecture for the warning on traffic incidents, co-driver alert (Ross et al. 2008) that provides hazard information, and driving guidance system—DGS (Yoo et al. 2008) that provides information about weather, speed, etc.

Navigation and guidance systems

Route guidance and navigation systems are perhaps the oldest and most commonly provided features in luxury cars. They use interactive displays and speech technologies. There exist several such systems in US, for example, TravTek, UMTRI, OmniTRACS, Navmate, TravelPilot, etc. (US Department of Transportation 1996).

GPS-based route guidance and navigation systems are very common nowadays. Low-cost GPS navigation devices are available which can be installed as an add-on. Furthermore, software and maps are available for GPS-enabled devices, such as mobile phones and PDAs.

The parking guidance or automatic parking, on the other hand, is very new area of research. However, such systems are now available in latest luxury cars due to their importance. For example, Toyota, BMW, Audi and Lexus are already using APGS in their luxury cars, and others are expecting to use it soon. Advanced parking guidance system (APGS) on Lexus LS (2007 model), for example, lets a vehicle steer itself into a parking space using in-dash screen, button controls, camera and multiple sensors, requiring very little input from the driver.

Mountable devices and displays

Users with ordinary vehicles, not older than 1996, may apply mountable devices and displays to supplement IVIS. These devices can be connected to the diagnostic port located under the dashboard. They can collect useful data about the vehicle and display it for the driver, such as speed, engine RPM, oxygen sensors, fuel economy, air-fuel ratio, battery voltage, error codes and so on. Examples of such devices include DashDyno SPD by Auterra, DriveRight by MicroDAQ, ScanGauge by Linear Logic, PDA-Dyno by Nology Engineering, etc.

Virtual dashboard (David 2006) is an important device developed by Toshiba. It is perhaps the most promising solution for information needs and infotainment. It consists of a real-time display controller (TX4961) and a dashboard display. Virtual Dashboard can handle all the information according to the current context. It can change the display to show a speedometer, tachometer, rear-view, navigation maps, speed or fuel-level.

Because of the limited functionality and high cost (US$ 300–400), mountable devices are not very much popular. However, mountable displays, being adaptive and multipurpose, are a major subject of research in HCI and interaction design.

Vision-based integration of ADAS

As mentioned before, vision-based integrated ADAS use cameras to provide multiple services for driver assistance. They are becoming very popular because of their low-cost and independence from infrastructure outside the vehicle. For example, an intelligent and integrated ADAS (Kim et al. 2008) uses only 2 cameras and 8 sonars, and others make use of only cameras (Fletcher et al. 2003; Trivedi et al. 2007; Nedevschi et al. 2007; Andrade et al. 2004; Finnefrock et al. 2005; Handmann et al. 2000). They present information through an in-vehicle display.

Specialized devices are also being introduced which can efficiently process visual data. For better situation awareness for drivers, different systems have been introduced to display the surrounding environment of the vehicle (Ehlgen et al. 2007; Cheng et al. 2007; Rakotonirainy et al. 2008; Pugh 2008; Liu et al. 2008b).

These recent developments show that the future lies in vision-based integrated ADAS. Current research mainly focuses on introducing traditional driver assistance systems based on camera, and then combining these individual systems into an integrated ADAS. After a careful analysis of the related projects, we find that the vision-based integrated ADAS (Ehlgen et al. 2007; Cheng et al. 2007; Rakotonirainy et al. 2008; Pugh 2008; Liu et al. 2008b), AIDE (Reding 2006) and Virtual Dashboard (David 2006) are very close to our proposed system. However, they leave many critical questions unanswered (Akhlaq 2010), for example, the problems of information-overloading and interaction design for vision-based ADAS etc, which is the main concern of our proposed system.

Technologies

For implementation of many ADAS functions, we need to capture information on speed, distance, relative position, direction of movement, and size and type of the neighboring vehicles or other objects on the road (Akhlaq 2010). For this purpose, several technologies are available, including Radar (radio detection and ranging), Lidar (light detection and ranging), Sonar (sound navigation and ranging), GPS (global positioning system), and video-based analysis. Table 1 provides a quick comparison of these technologies. However, we will explain video-based analysis in more details as our proposed system uses it.

Video-based analysis uses digital cameras to get a digital image of the surroundings of a vehicle. A digital camera uses an image sensor device—either charge-coupled device (CCD) or complementary metal-oxide semiconductor—CMOS (JISC Digital Media 2011)—that changes an optical image to an electrical signal. The captured video is processed in real-time to calculate speed, direction, distance, and size and type of objects appearing in any image or frame. This information is sufficient to implement most of the functions of an advanced driver assistance system (ADAS). Figure 1 shows some examples of tiny image sensors available in the market.

Camera-based systems are generally considered inaccurate and inappropriate in poor visibility conditions such as fog, dust, rain, and particularly snow. However, many efficient techniques are now available for bad weather conditions. Moreover, infrared or radar enabled CMOS cameras are now available which can better solve these issues. They are more expensive than ordinary cameras at present, but will become cheaper very soon. The performance of CCD and CMOS image sensors is compared in Table 2.

We can conclude from Table 2 that CCD has better quality, resolution and light sensitivity, but CMOS is also improving in these terms. CMOS is already a faster, smaller, cheaper, simpler and power efficient technology. CCD cameras are usually used as rear-view because they perform better in dark environment, whereas CMOS cameras are used for advanced driver assistance systems because of their higher image rate. The overall trends in the automotive industry show that CMOS cameras will dominate the market in future (JISC Digital Media 2011).

Now we briefly explain video-based analysis to show how monocular vision (i.e., single camera mounted on a vehicle) can capture the required information for implementing ADAS functions, particularly speed, distance, relative position, direction of movement, and size and type of the neighboring vehicles or other objects on the road.

For on-road object recognition, such as obstacles, pedestrians, vehicles, road signs and lane markings, a two-step method is used. First, a hypothesis is generated—hypothesis generation (HG), and then this hypothesis is verified—hypothesis verification (HV). That is, a supposition is made about the location of some object in the picture first and then the presence of that object is verified. A large number of methods exist for HG and HV, which use different kind of knowledge about the object under consideration, and are classified in Table 3 accordingly. Although object detection and tracking has improved a lot, the roadside structures, such as buildings, tunnels, overhead-bridges and billboards still offer enhanced difficulty for recognition of vehicles, pedestrians and road-signs. Because many fatal accidents occur due to unnoticed objects in the blind spot, BSD is even more important. We can further improve object detection by adding some kind of tracking mechanism in it.

The traffic sign recognition also goes through two steps: sign detection, and classification. A sign detection technique identifies all the areas in a picture where some road-sign is expected or present, and then inputs these identified areas to the classification module in order to recognize the type of road signs. A very good recognition rate had been achieved a decade ago and now its accuracy is improved to "almost" 100% (Piccioli et al. 1996).

The lane detection and tracking is another important function in automotive applications such as LDW and environment reconstruction. Lane-boundaries are indicated by painted-lines, reflectors or magnetic markers embedded into the center of road. However, painted-lanes are more common because they are economical to make, and are easy to detect and track using camera because of their higher intensity. A video camera is installed in the front of a vehicle, which can see the road for more than 25 m depending on the range of camera.

It is relatively new idea to measure the distance of objects from a vehicle using digital camera, which has lower cost and several applications. It is very common to use optical flow (i.e., change of object position between two pictures) to measure distance and direction of an object using single camera. However, we can also use several cues such as size and position of objects, lane width, and point of contact of a vehicle and the road. The last cue is more useful because other cues have a very large variation, for example, width of a vehicle may vary from 1.5 to 3 m. Liu et al. (2008a) suggest to use Sobel edge-enhancement filter combined with

Table 1 Commonly used technologies for implementing ADAS functions

	Radar	Sonar	Lidar	GPS	Video-based analysis
Technology	Radio waves (300 MHz–30 GHz)	Sound waves (infrasonic to ultrasonic)	Laser or infrared light	24–32 satellites transmit location as radio signals	Image sensors (CCD or CMOS)
Measures	Speed, distance, direction	Speed, distance, direction, size	Speed, distance, shape	Speed, direction, relative position (distance from a specific point)	Speed, distance, relative position, direction, size & type
Range (approximate)	150 m	7 feet	25 km	Global availability	25 m (depends on camera)
Methods/principles	Doppler shift analysis, Time of flight (ToF)	Doppler shift analysis, Time of flight (ToF)	Doppler Effect, Time of flight (ToF), etc.	Trilateration	Image Processing, Pattern matching, etc.
Example systems	VORAD—vehicle on-board radar (Woll 1995)	Dolphin SonarStep by Echomaster	A system produced by Sick AG	Pothole Patrol—P^2 (Bergasa et al. 2006) for path-holes, and Co-Driver Alert (Bertozzi et al. 1998) for hazard information	Wraparound View by Fujitsu and EyeQ2^{TM} by Mobileye
Pros	Reliability, accuracy, and ability to work in any weather conditions	Ability to work under water and on the surface as well	Accuracy, low cost, object recognition and night-vision	Global availability	Low cost, high availability, several applications, usable as an add-on, can be combined with other systems, infrastructure—independent, and easy to manage
Cons	High cost, absorbents, ghost objects, inability to distinguish objects, limited field-of-view ($\leq 16°$), and low lateral-resolution may find incorrect target (Nashashibi et al. 2008)	Sound absorbents, and inaccurate distance measurements during wind gusts, snow, rain, etc.	Interference by light in the surroundings, infeasibility for bad weather conditions, limited field-of-view, and degradation in performance by snow reflections	Bad performance in urban areas with high buildings etc., low accuracy (1–5 m in open areas), selective availability due to US military control over GPS, and receivers have high cost and fairly long start-up time, i.e., ≤ 45 s (Porcino 2001)	Weather-dependency, lower accuracy, and immature technology

the optical flow to detect the vehicle in front and find the distance by using headway distance estimation model. The distance between the host and preceding vehicle can be calculated as:

$$d_2 = \frac{H \times f_c}{P_r \times (Y_{\mathrm{HV}} - \frac{\Delta R}{2})} - d_1$$

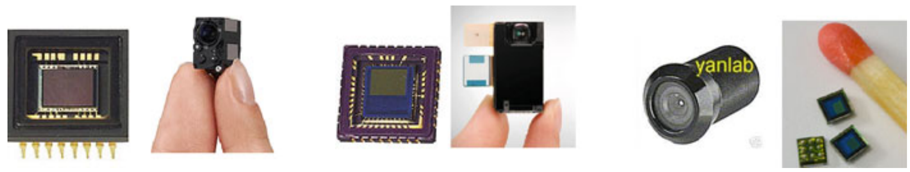


Fig. 1 Some examples of tiny image sensors and cameras. **a** 1/3-inch CCD image sensor by Kodak, **b** a small 2-mp CCD camera by Sharp, **c** 1/4-inch CMOS image sensor by Sony, **d** a small 8-mp CMOS camera by Samsung, **e** an infrared-enabled CMOS camera by Yanlab, **f** 7 × 7 pixel CMOS camera with ultra-wideband Radar

Table 2 Performance comparison of CCD and CMOS image sensors used for video-based analysis

Performance parameters	CCD	CMOS
Dynamic range (luminance range it can capture)	High	Moderate
Noise	Low	Noisier (but getting better)
Light sensitivity (ability to work in darkness)	High	Lower
Uniformity	Better	Worse (but getting better)
Windowing (sub-regions)	Limited support	Fully supported
Image rate (speed)	Lower	Higher
Image quality	High	Lower (but comparable now)
Age of technology	Mature	Newer
Power consumption	High (100 times)	Low
Reliability	Moderate	High
Pixel size	Smaller (better)	Larger
System size	Larger	Smaller
Architecture	External circuitry required	All circuitry on one chip (“camera-on-a-chip”)
Flexibility	High	Low
Signal type	Analog	Digital
Manufacturing	Complex	Simple
Cost / price	Expensive (little bit)	Inexpensive
Example applications	Digital photography, broadcast-tv, industrial/scientific/medical imaging, etc.	Cameras for mobile devices, computers, scanners, fax-machines, bar-code readers, toys, biometrics, vehicles, etc.

where d_2 is the distance to be measured, H is the camera height from ground, f_c is its focal-length, d_1 is its distance to the front-tip of the vehicle that is hosting camera, P_r is pixel-width in the monitor or display device, ΔR is image width, and Y_{HV} is the coordinate of image in row direction of the preceding vehicle's bottom end-point as shown in Fig. 2.

As the accuracy of distance measured by digital camera is not enough for crash avoidance systems, there have been some efforts to incorporate radar capabilities into CMOS camera for 3D imaging. For example, Canesta's CMOS image chip automatically finds the distance to every object in a sight at once using time-of-flight calculations on each pixel (Johnson 2006). The main advantages of this technology are that it is highly accurate and works in all weather conditions.

The speed and direction (i.e., velocity) of moving objects in a scene can be calculated by optical flow and tracking of objects for a while. However, this method is not accurate when compared to radar-enabled CMOS camera (Johnson 2006). Another innovative approach is based on motion blur or smearing effect, which occurs because of the relative motion between the camera and the objects. Li et al. (2008) have proposed a method to calculate direction and speed of the moving object using a single motion-blurred image. The relative speed is calculated using this formula:

Table 3 Summary of methods/techniques for obtaining required information for implementation of camera-based ADAS functions

S#	Function	Methods/techniques	Brief description	Comments
1	On-road object recognition (hypothesis generation methods)	Model-based or knowledge-based methods (Hoffmann et al. 2004)	Use shadow, corners, texture, color, light, symmetry, and geometrical features etc.	Popular approach due to simplicity and high performance
		Stereo-based methods (Franke and Kutzbach 1996; Bertozzi et al. 1998)	Use dual camera based techniques such as disparity-map (Franke and Kutzbach 1996) and inverse perspective transform	High computation cost and low processing speed
		Motion-based methods (Giachetti et al. 1998)	Use optical-flow or some other method combined with it	Difficulty in detecting still or slow-moving objects
		Context-based methods (Torralba 2003)	Use the relationship between the objects and the scene	Require scene analysis which makes it slow
		Feature fusion-based methods (Zhu et al. 2005)	Combine two or more methods mentioned before	Improved accuracy
		Adaptive frameworks (Kim et al. 2008)	Adapt and select feature according to the situation	Generic and better approach
	On-road object recognition (hypothesis verification methods)	Template-based methods (Handmann et al. 2000)	Exploit correlation with existing patterns such as color, edges, shapes, corners etc.	An effective method
		Appearance methods (Torralba 2003)	Use feature extraction by principal component analysis (PCA) etc, and classification by neural network etc.	Better performance
		Hybrid techniques (Cao et al. 2008)	Mix two or more techniques	Better performance than other two methods
2	Traffic sign recognition	Sign detection methods (Piccioli et al. 1996; Zin et al. 2007)	Use color-segmentation, perspective view, 3D modeling and scene understanding etc.	Almost 100% accurate
		Sign classification methods (Piccioli et al. 1996; Zin et al. 2007)	Use region of interest (ROI) for detection and pattern recognition for classification	Almost 100% accurate
3	Lane detection and tracking	Feature-based methods (McCall and Trivedi 2006)	Detect a particular characteristic of lane boundary such as color, contrast, edge, or texture etc.	Moderate accuracy
		Model-based methods (Lim et al. 2009; Wang et al. 2006)	Detect a lane boundary using some model that is based on, for example, Kalman filter, neural network, inverse perspective transform (IPT), template matching and Gaussian filter etc.	Moderate accuracy
		Hybrid methods (Su and Fan 2008)	Combine two or more techniques such as Hough Transformation, road model, gray scale statistics, dynamic range of interesting (ROI), and lane features etc.	ROI-based hybrid approaches perform better

Table 3 continued

S#	Function	Methods/techniques	Brief description	Comments
4	Distance	Cue-based approaches (Stein et al. 2003)	Use size and position of on-road objects, lane width, gray intensity, and point of contact (PoC) of a vehicle and the road	Better to use PoC of a vehicle and the road for an accuracy of 95% at 45 m
		Optical-flow (Shibata et al. 2008)	Considers the change of objects' position between two pictures	Low accuracy
		Model-based estimation (Liu et al. 2008a; Fritsch et al. 2008)	Headway distance estimation model uses Sobel edge-enhancement filter along with the optical flow, while others use EKF-based fusion (Extended Kalman Filter) or perspective model	Fast but moderately accurate
		Radar-enabled CMOS cameras (Johnson 2006)	Use time-of-flight method on each pixel	Highly accurate and weather-independent
5	Speed & direction	Optical-flow (Martinez et al. 2008; Li et al. 2008)	Measures and/or tracks the change of objects' position in two frames	Low accuracy
		Smearing effect (Li et al. 2008)	Uses a single motion-blurred picture	Low accuracy
		Radar-enabled CMOS cameras (Johnson 2006)	Use time-of-flight method on each pixel	Highly accurate and weather-independent
6	Drowsiness detection	Eye-and-head tracking (Smith et al. 2003; Devi and Bajaj 2008)	Tracks the driver's eye and head to find her visual attention	About 90% accurate
		Event-detection (Albu et al. 2008)	Observes the eye-state using a template-matching algorithm	About 85% accurate
7	Environment reconstruction	Integrated video (Zoratti 2011)	Combines live-video from many cameras to provide a broader view of the surrounding areas	Very low usability in road-safety applications
		Bird's-eye view (Kim et al. 2008; Trivedi et al. 2007; Ehlgen et al. 2007; Cheng et al. 2007; Liu et al. 2008b; Ehlgen and Pajdla 2007; Brauckmann et al. 1994; Toyota et al. 2000; Ichihara and Ohta 2000)	Provides a quick overview of the surrounding areas by reconstructing it on a display	Innovative and highly effective

$$v = \frac{zKs_x}{Tf\cos\theta}$$

where z is the distance from camera to the object, K is the blur-length in pixels, s_x is the width of a camera-pixel, T is the shutter speed, f is the focal length of camera, and θ is the angle when object is not moving parallel to the image plane as shown in Fig. 3.

Drivers' fatigue or drowsiness is easily identifiable from their head position and eye closure. However, vigilance or attention is different from fatigue; driver may be looking off the road or involved in some other activity while being fully awake. A single camera mounted on the dashboard, for example, can help detect both drowsiness and vigilance. Currently, drowsiness detection methods are about 90% accurate. More research in this area will produce some highly accurate methods in near future.

For environment reconstruction, we can process images from all the cameras around a vehicle and provide a bird's-eye view that is a quick overview of the surroundings. This is essentially not a simple integrated video, which is of no use for drivers. Many systems have been introduced which provide an overview of the surrounding area of a vehicle (Kim et al. 2008; Trivedi et al. 2007; Ehlgen et al. 2007; Cheng et al.

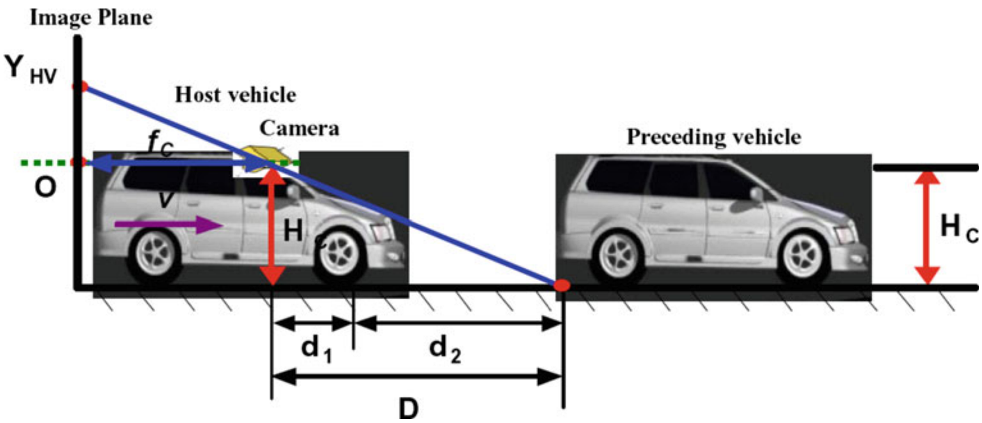


Fig. 2 Distance estimation model (Liu et al. (2008a))

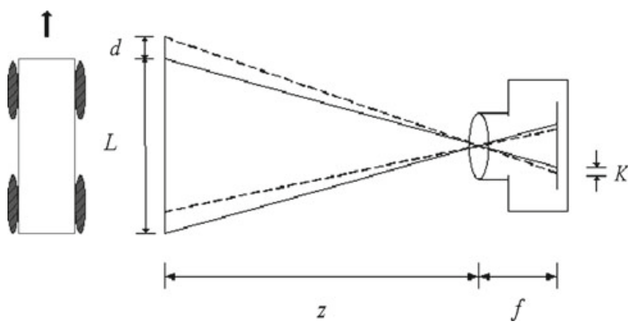


Fig. 3 Distance estimation using smearing effect (Li et al. 2008)

2007; Liu et al. 2008b; Ehlgen and Pajdla 2007; Brauckmann et al. 1994; Toyota et al. 2000; Ichihara and Ohta 2000). Our proposed system also provides the bird's-eye view in addition to other functions of ADAS using digital cameras.

In the following section, we provide an architecture and design of the proposed ADAS system along with a basic prototype.

The system design

Equipped with digital camera technology, our proposed system monitors its surroundings and processes video frames in order to find distance, velocity, position, and size and type of all the neighboring objects. This information is then used by different ADAS modules to assist the drivers and to generate bird's-eye view of the surroundings. Our design puts technologies—such as cameras, digital image processor, and a thin display—into a smart system in order to offer ADAS functions.

Our proposed system would help drivers in maintaining a safe speed and safe distance, avoiding any collision, keeping them alert, recognizing road signs, detecting blind-spots, keeping their lane, identifying pedestrians, enhancing their vision at night, and warning them of the dangerous situations in a distraction-free way.

Design considerations

Although ADAS are combination of hardware and software, they are essentially different in nature and use. They are life critical systems whose failure may result in death or injury to people, damage to the system itself, and harm to the environment. Therefore, while designing our proposed system, we have considered a number of issues as follows.

Driving environment

A system for drivers should have a design that is easy to use, require very less user attention and take minimum time to complete a task (Nakamura 2008). These requirements give rise to special issues that must be resolved while designing an ADAS.

First, a distraction of only a few seconds may result in a vital road-accident. For example, a large text message on a display would require much attention from user, and hence be avoided. Therefore, the system should convey information to drivers using standard symbols (such as standard road signs, and common symbols for objects or events etc.) or other methods requiring minimal user attention. Furthermore, the system should display any information within the visual approach of drivers because they cannot keep their attention away from road for more than a few seconds.

Second, not all the drivers are well educated and computer literate. Therefore, the system should require little or no training, troubleshooting and administration.

Third, the system should not have a major effect on driving activity itself, i.e., it should let drivers drive their cars as they have always done unless there is a major problem. The system should fit into the driver environment rather than enforcing it like an office system. It should not only accommodate the wide range of driver's activities but also support them.

Fourth, such a system should have low cost especially when it is being introduced as an add-on; an expensive system may not be bought and used by drivers.

Fifth, being a life-critical system, the system must be safe and reliable. As the system does not employ redundancy, any hardware failure should safely shut down the system and inform the user. Similarly, the complexity of software and unexpected conditions may cause software failure leading to a dangerous situation. Therefore, the system should use exception handling to avoid any software failure.

Finally and the most importantly, the system must follow the guidelines set by different governmental bodies issuing a set of requirements for systems regarding road-safety (US Department of Transportation 2004; Nakamura 2008).

Camera positions

Selecting a proper location for mounting a camera is an important issue in camera-based automotive applications. These cameras should be able to see the environment without any obstruction.

Accordingly, a camera in front is required to capture the road curvature, lane boundaries, road-signs, vehicles and other objects. A camera in the rear is required to detect lane-boundaries and objects in the blind-spots and behind the vehicle. The cameras on two sides of the vehicle are required to detect objects in the blind-spots and on both sides of the vehicle. In this way, a blind-spot on each side of the vehicle is covered by two cameras with some overlapped view.

For security and performance, the front and the rear cameras are mounted on the windscreens inside the vehicle. The cameras on two sides are embedded into the side-view mirrors or at some upper location so that they can see the road directly below them. The fifth camera is installed on the dashboard inside the vehicle that will look at the driver for drowsiness and vigilance.

Issuing an alert or warning

On detecting some dangerous situation, the system should issue an alert. There are four kinds of alerts issued by different automotive applications: auditory, visual, haptic, and automatic (i.e. takeover the control from driver). However, it is important to choose wisely from different types of alerts or warnings.

We have considered visual and auditory alerts only because our system employs only image sensors. A display should issue any visual alerts while pre-installed speaker or beeper should play auditory alerts.

By default, the system should blink symbols for vehicles and other nearby objects on the display. However, in dangerous situations, it should also issue auditory alerts using beeps of low or high volume depending on the level of danger.

User interface and interaction

While installing a display, it must be a prime concern that the display is viewable and within the reach of driver. There are two main issues regarding user interface here: placement (i.e. where to put it) and the mode of interaction (i.e. to use either buttons or touch-screen).

There are four possible locations for mounting the display as for as placement is concerned (Jonefjäll 2009): Head-Up Display (HUD) on the windscreen, Driver Information Module (DIM) inside the dashboard behind steering, Rear View Mirror (RVM), and Infotainment Control Module (ICM). However, in our case we can opt from two locations only, i.e., HUD or DIM. As we do not use any kind of projection device, DIM is the best suitable place for display.

Touch screen is an appropriate mode of interaction where user can touch the screen to make selections. The user interface screen provides the following options on startup:

1. Change my settings—(it has 3 sub-options)
    a. Change level of expertise – learner, beginner, experienced, or expert.
    b. Type of warnings to be issued—none, auditory, visual, or both audio-visual
    c. Volume of the sound for auditory alerts—anywhere from silent to loud
2. Remove my settings—(users are known by face-recognition and have different settings)
3. Start camera calibration—(required at the time of installation or after a damage)

These options appear for a few seconds on the startup and then disappear in favor of default settings. However, on touching the screen, these options appear again. The default settings are as follows: level of expertise = experienced, type of warning = both audio-visual, volume of the sound = medium. The system manages and remembers settings for each user by identifying their faces through the fifth camera installed on the dashboard.

The proposed system uses single display that is multipurpose and adaptive. It shows the highest priority information at any instance of time. For example, at startup, it shows options' screen; on recognizing some traffic signs, it displays the signs; and for most of the time, it displays reconstructed environment along with speedometer as shown in Fig. 4.

A user can initiate interaction by touching the screen. However, five cameras make the system aware of its users and context. This awareness makes it possible to adapt the system according to the situation and minimize the annoyance by lowering the level of input required of the user. For these reasons, the system should continuously learn from the interactions and use this learning in future decisions. For

Fig. 4 An integrated and adaptive interface of the proposed system. **a** Options displayed at startup, **b** traffic signs and speedometer, **c** reconstructed environment and speedometer

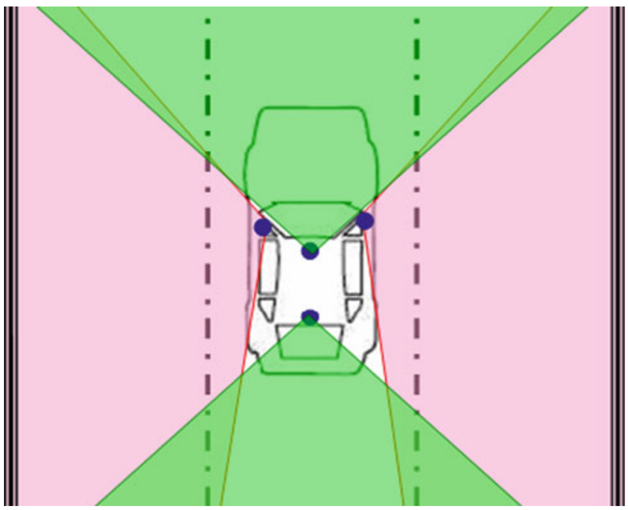


Fig. 5 Camera positions shown as dots (5th camera is inside)

example, the system should automatically update the expertise level of the driver with the passage of time.

Components of the system

The proposed system has three components: Hardware, Middleware, and Applications. We have used five-layered architecture (Baldauf et al. 2007) of context-aware systems, which consists of Physical, Data, Semantic and Inference, Management, and Application layers. All the layers between Physical and Application layer are jointly called as middleware.

Hardware components of the system are five CMOS cameras or image sensors, a digital processor, and a TFT-LCD display (thin film transistor liquid crystal display). The system is equipped with four cameras installed on all the four sides of vehicle (as shown in Fig. 5) to provide 360° or all-around coverage of the surrounding areas, and the fifth camera is installed inside the vehicle to look at driver for drowsiness and attention. The system uses a digital processor (ordinary computer or a digital signal processor chip) for applying image-processing techniques on video frames to get the required information for ADAS modules. The 360° or all-around view is then processed for environment reconstruction and is displayed on TFT-LCD display mounted on the dashboard at driver information module (DIM) location that is just behind the steering. However, it could also be projected on head up display (HUD) location if some projection device was available. We propose an adaptive display that can be used for speedometer, odometer, temperature, time, fuel-gauge, and other vehicle data according to the context.

Middleware is the software part of system that provides a variety of functionality such as supporting different types of sensors, retrieving the raw sensor data, pre-processing of the sensor data, and then storing, sharing, distributing or publishing the processed data. In our proposed system, real-time video frames captured by the five cameras are instantly sent to the middleware for noise removal, enhancement, transformation, fusion, etc. These frames are then processed for calculating the distance, speed, direction, position, and size and type of all the objects appearing in a scene. This processed information is then pushed up to the application layer.

Application layer hosts a number of application modules for driver assistance. These application modules provide twelve commonly used ADAS functions. The implementation detail of these modules is provided in the following section.

System design

The proposed system implements a number of ADAS functions. This section explains how different components of the system work together. Figure 6 provides an overview of the proposed system.

At physical layer of the system, image sensors capture real-time video of the surroundings. This video or image sequence is then sent to the middleware that performs a number of pre-processing operations, such as noise removal, image enhancement, transformations, image fusion, etc. In addition to pre-processing, middleware also measures the distance, speed, direction, position, size and type of all objects appearing in a scene. These measurements are then made available to application layer that hosts a number of application modules such as ACC, ISA, FCW, LDW, TSR, BSD, etc. These application modules provide ADAS functions using camera-based methods for object recognition (i.e. vehicle, pedestrian, and obstacle), road sign recognition, lane detection and tracking, distance measurement, speed and direction measurement, driver drowsiness detection, and environment reconstruction.

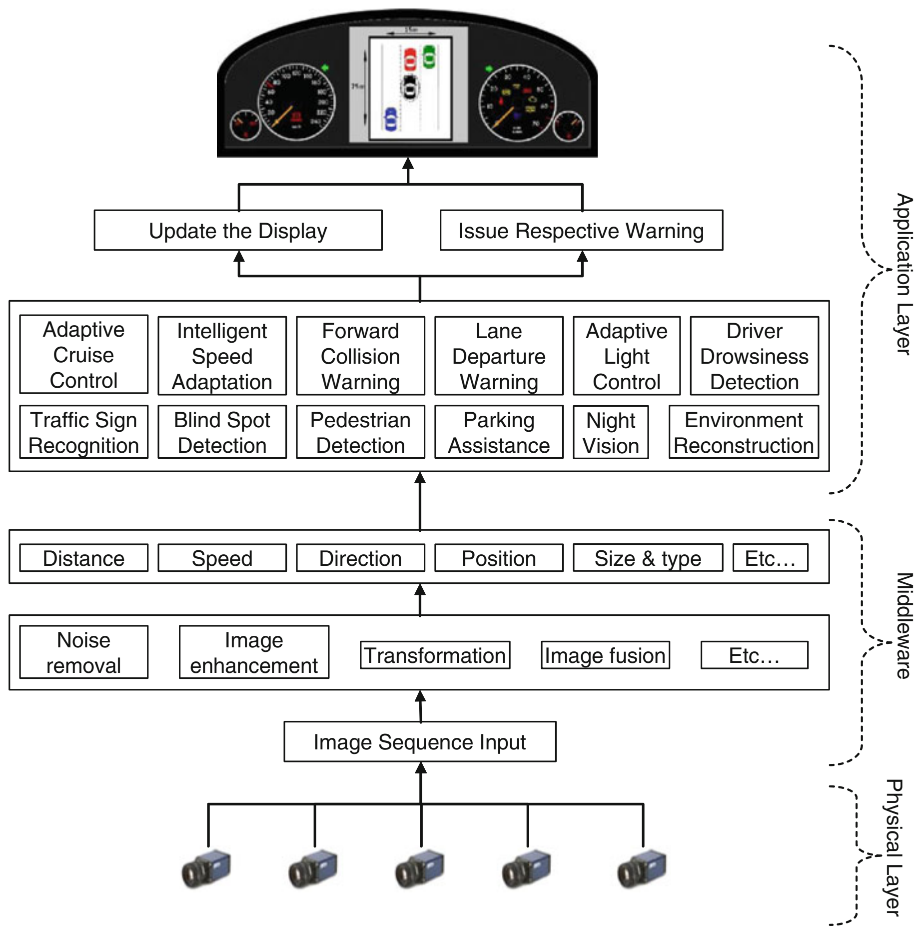


Fig. 6 Overview of the proposed system

In the following sections, we present system design for individual ADAS functions.

Adaptive cruise control (ACC)

Adaptive cruise control system automatically slows down the vehicle when it approaches another vehicle in front and accelerates again to achieve the preset speed when traffic allows. Traditional ACC systems use laser or radar technologies to measure the distance and speed of the vehicle in front. However, we have proposed a camera-based implementation of ACC as shown in Fig. 7.

After finding the speed of vehicle in front, it finds the local speed and the headway distance. It issues a warning and/or reduces the local speed in order to avoid forthcoming collision if Time to Contact (ToC) is too small. Here, we implement vehicle detection using only camera-based methods as shown in Fig. 8.

The vehicle detection module extracts some candidates, validates them, and then tracks those candidates for some time by getting help from lane detection module. At the end, it classifies objects as, for example, bicycle, motorcycle, car, bus or truck.

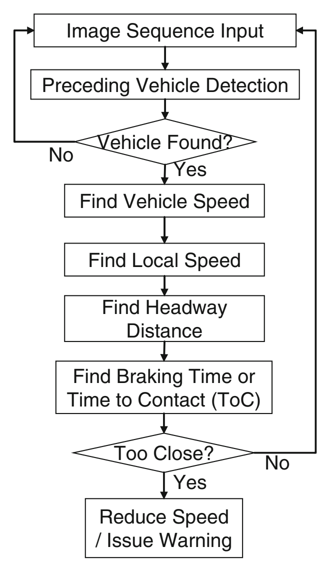


Fig. 7 Adaptive cruise control system

Intelligent speed adaptation (ISA)

Intelligent speed adaptation system continuously observes the vehicle speed and the local speed limit on a highway and

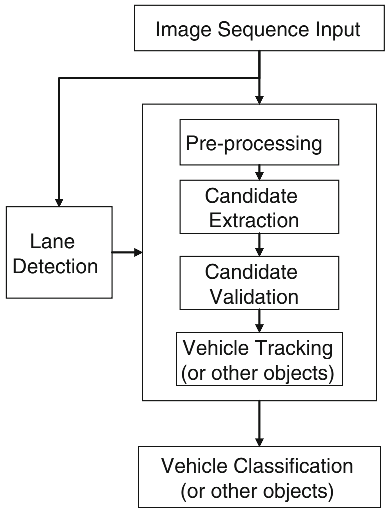


Fig. 8 Vehicle detection (or other objects)

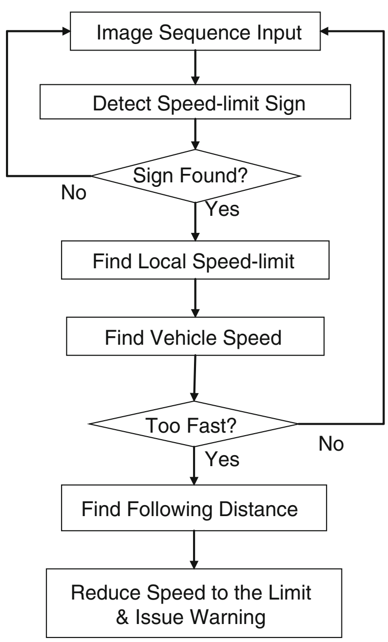


Fig. 9 Intelligent speed adaptation system

then advises or takes an action when the vehicle exceeds the speed limit. Traditionally, a GPS is used to determine the local speed limit on a road, but we have proposed a camera-based implementation of ISA as shown in Fig. 9.

The ISA system looks for any speed-limit sign on the road, and compares the speed limit with the speed of vehicle. If the vehicle is too fast, it issues a warning and reduces the vehicle speed while keeping an eye on the vehicles behind to avoid rear-collision.

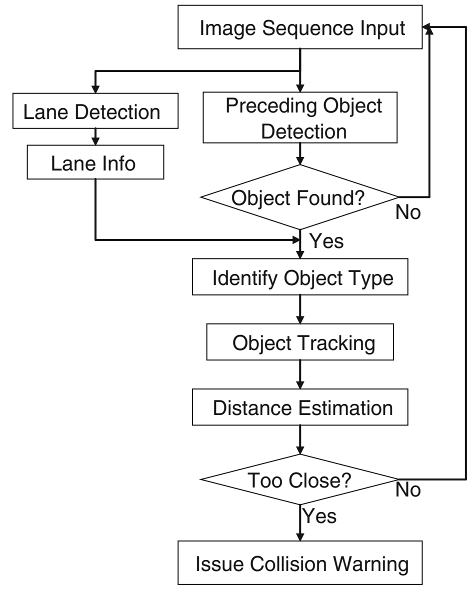


Fig. 10 Forward collision warning system

Forward collision warning (FCW) or collision avoidance

Forward collision warning or avoidance system detects objects on the road that would otherwise go un-noticed and warns its driver of any possible collision with them. Traditional FCW systems use infrared and radar technologies to detect objects on the road, but we have proposed a camera-based implementation of FCW as shown in Fig. 10.

The FCW system detects any objects in the same lane, calculates distance between the object and the vehicle, and issues a collision warning in order to avoid accident if the distance is quickly becoming shorter than a threshold value. In this way, FCW will issue collision warning only when it finds that the vehicle will collide with another vehicle or object if it continues to move with the current speed.

Lane departure warning (LDW)

Lane departure warning system constantly observes the lane markings and warns a driver when the vehicle begins to move out of its lane without turning on its indicator. A similar system, Lane keeping assistance (LKA), helps driver in keeping the vehicle inside a proper lane. Traditional LDW systems use light or magnetic sensors to detect reflections from reflectors or magnetic field produced by the embedded magnetic markers respectively. However, we have proposed a camera-based implementation of LDW as shown in Fig. 11.

The LDW system detects and tracks lane markings, predicts lane geometry, finds any deviation from path, and issues lane departure warning or lane keeping action while keeping an eye on the vehicles behind to avoid rear-collision. This

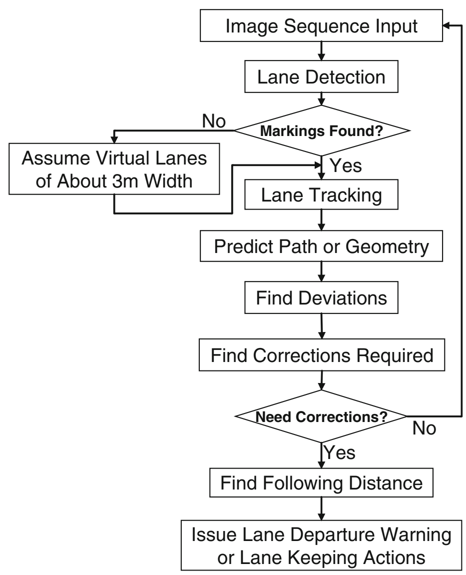


Fig. 11 Lane departure warning system

system works even in the absence of lane markings. In this case, it assumes virtual lanes of about 3 m width.

Adaptive light control (ALC)

Adaptive light control system moves or optimizes the headlight beam in response to a number of external factors, such as vehicular steering, suspension dynamics, ambient weather, visibility conditions, vehicle speed, road curvature, contour, etc. Traditional ALC uses a large number of electronic sensors, transducers and actuators. However, we have proposed a camera-based solution for finding environmental factors for ALC as shown in Fig. 12.

The ALC system determines driving context, such as any approaching vehicle, environmental lighting, local speed of the vehicle, and path turnings in order to adapt headlights accordingly. It then sends appropriate signal to the light controller for turning the lights dim, bright or bend depending on the context.

Parking assistance (PA)

Parking assistance system helps drivers avoid any collision while parking their vehicles. Some systems takeover the steering and actively park the vehicle, while others provide a live view of the surroundings and issue a warning in case of forthcoming collision. Such systems are new to automobiles and usually use cameras. We also propose a camera-based PA system as shown in Fig. 13.

The PA system identifies any objects in the very close proximity of vehicle, tracks them to find their distance, and issues a collision warning if the vehicle comes very close to the objects.

Traffic sign recognition (TSR)

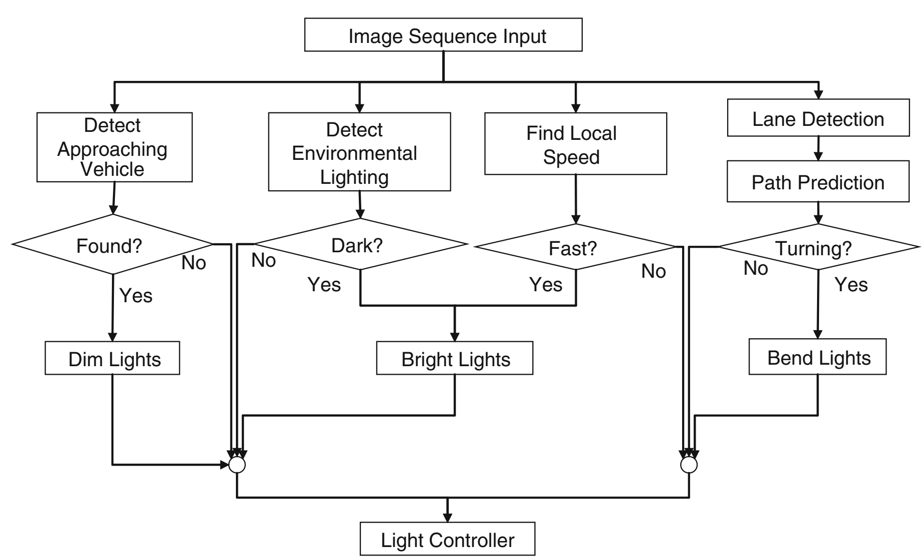
Traffic sign recognition system identifies any road traffic signs and warns the driver to act accordingly. Traditional TSR systems use GPS or radio technologies to determine the traffic signs. However, we propose a camera-based TSR as shown in Fig. 14.

The TSR system selects a region of interest (RoI), finds and tracks any candidates, extracts features, and classifies the sign. It then shows this sign on the display, if valid.

Blind spot detection (BSD)

Blind spot detection system helps avoid accidents when changing lane in presence of other vehicles in the blind spot. It actively detects any vehicles in the blind spot and informs

Fig. 12 Adaptive light control system



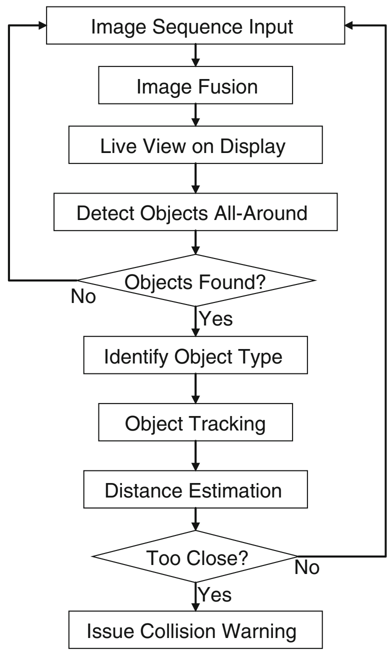


Fig. 13 Parking assistance system

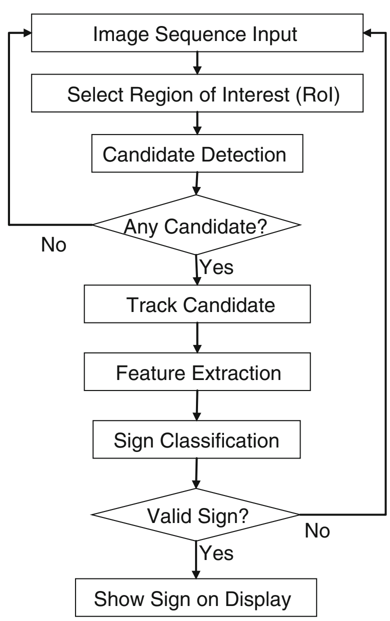


Fig. 14 Traffic sign recognition system

the driver before taking a turn. Traditional systems use sonar, radar, or laser, whereas we propose a camera-based implementation of BSD as shown in Fig. 15.

The BSD system first finds the lane markings, detects any vehicles in the blind spots, finds their speed, distance, direction, size and type, and issues warning if required and updates the display according to the reconstructed environment.

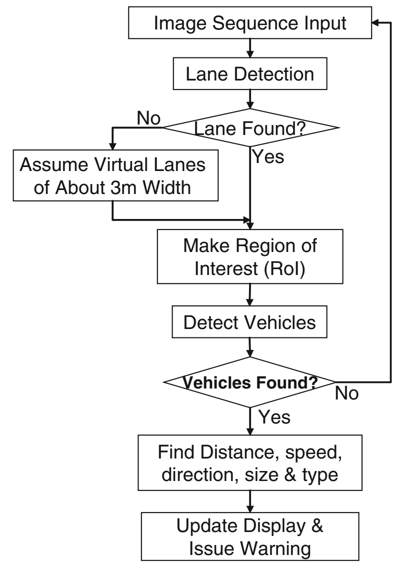


Fig. 15 Blind spot detection system

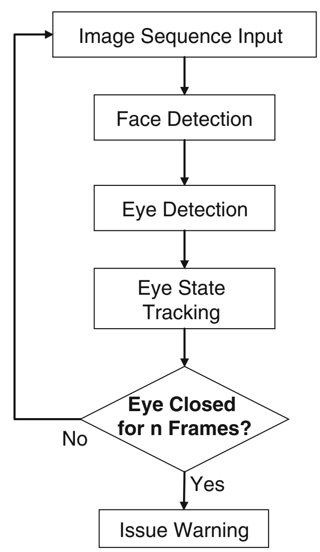


Fig. 16 Driver drowsiness detection system

Driver drowsiness detection (DDD)

Driver drowsiness detection system detects a drowsy or sleeping driver and awakes her to avoid any accident. Traditional systems use a number of sensors such as stress sensor for finding grip on steering, and other sensors to find physiological state, such as heart-beet, blood pressure, and temperature of the driver. However, we propose a very simple camera-based implementation of DDD that detects eye closure as shown in Fig. 16.

The DDD system first detects human face, then eyes, and then tracks eye state. It issues a warning if it finds closed eyes in more than n consecutive frames (n is usually near 10).

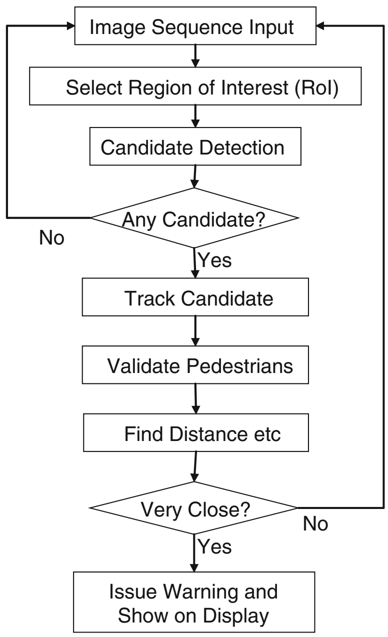


Fig. 17 Pedestrian detection system

Pedestrian detection (PD)

A pedestrian detection system identifies any human walking on or near the road and alerts the driver to avoid any collision. Traditional systems use sonar, radar, or laser technology. However, we propose a camera-based implementation of PD as shown in Fig. 17.

Our proposed PD system works like a TSR system. It detects human by symmetry or motion. However, it also issues warning and highlights pedestrian symbol on the display if someone is very close to the vehicle. Humans are the most valuable assets on the road and the governments in near future will enforce pedestrian detection systems. Therefore, future cars will have PD as compulsory module.

Night vision (NV)

Night vision system helps a driver in seeing objects on the road during night or poor weather. Traditional systems use infrared or radar technology to detect objects on the road and use a projector for head-up-display (HUD). However, we propose a camera-based implementation of NV as shown in Fig. 18.

We use ordinary CMOS camera for object detection and a TFT-LCD display for showing these objects. Its performance can be improved by using cameras with wide dynamic range—WDR (Hertel et al. 2008) of more than 120 dB that can handle both bright and dark environments.

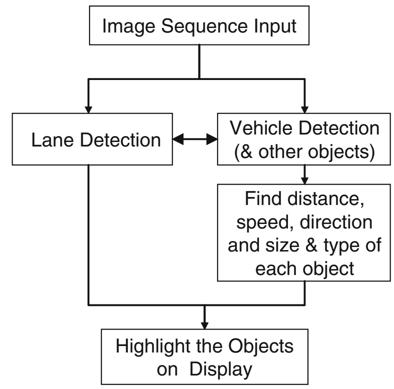


Fig. 18 Night vision system

Environment reconstruction (ER)

Environment reconstruction system identifies all the neighboring objects on the road, including lane markings and vehicles, and finds their speed, distance, direction, and size and type. It then reconstructs the environment and draws it on the display. The idea of environment-reconstruction is very new. It fuses camera and some other type of sensors such as infrared, radar and laser. However, we propose a camera-based implementation of ER in the Fig. 19a.

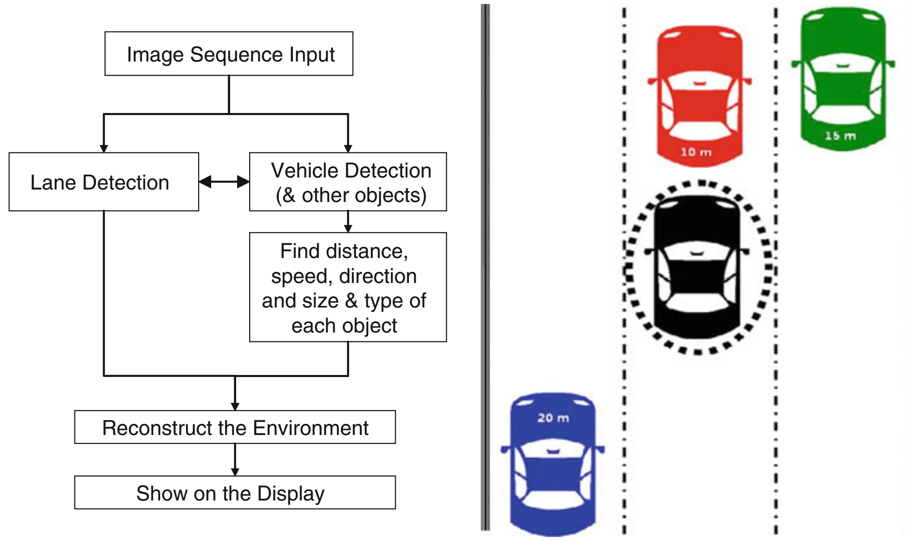
The ER system identifies lanes and other objects around the user (encircled vehicle) and reconstructs the environment on a display as shown in Fig. 19b. A very close object is displayed in red and blinked fast in order to alert the driver.

Implementation of prototype

A full-fledged implementation of the proposed system is not yet done. The implementation, testing and performance evaluation shall be done in the next phase of project. However, we have developed a basic prototype using ordinary CMOS cameras (8 mega-pixels) and a laptop (P-4, 2.0 GHZ, dual-core). We use video and image processing tools available in MATLAB R2007a or newer versions (Computer Vision System Toolbox 2011).

We demonstrate only the most important functions, such as detection of pedestrians, vehicles and lane markings, measurement of speed and distance, and recognition of traffic signs, which make the basic elements of all ADAS systems. For example, LDW system can be implemented by continuously observing the distance of vehicle from the center of a lane and issuing a warning when a departure on left or right lane markings is detected.

The image frame shown in Fig. 20 is used as an input to the system. It contains a number of relevant objects such as vehicles, traffic signs, pedestrian and lane-markings etc. A separate copy of the input frame is provided to the different modules simultaneously.



(a) (b)

Fig. 19 Environment reconstruction system and the display. **a** Environment reconstruction system, **b** the reconstructed environment

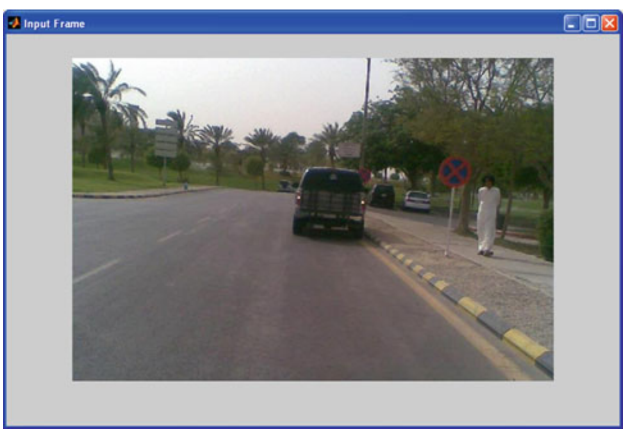


Fig. 20 Input frame for the prototype

We use two-step method for on-road object recognition. In the first step, i.e., hypothesis generation (HG), we use model-based or knowledge-based method (Hoffmann et al. 2004) that exploits the symmetry and motion properties of objects in order to find candidate objects in the input frame. In the second step, i.e., hypothesis verification (HV), we validate the presence of any objects using template-based method (Handmann et al. 2000) that exploits the correlation with existing patterns such as color, edges, shapes, and corners etc.

Accordingly, the Pedestrian Detection module successfully detects the presence of a human on footpath using shape properties such as head, body, and legs etc (Fig. 21a), Vehicle Detection module detects the presence of all four vehicles in the frame using shape property of vehicles (Fig. 21b), Road Sign Detection module detects two *"No Parking"* signs using color and shape properties of traffic signs (Fig. 21c), and Lane-marking Detection module detects the painted lanes on both sides of the vehicle carrying the camera using color, edge and intensity properties (Fig. 21d).

The output of different functions is then merged together into a single image (Fig. 22) by repeatedly using the *wfusimg* function available in Wavelet Toolbox of MATLAB.

In addition to these visible outputs, we also perform some calculations regarding distance and speed of objects in the input frame using model-based estimation (Liu et al. 2008a; Fritsch et al. 2008) that employs Sobel edge-enhancement filter and optical-flow. However, this method has moderate accuracy but it is much better than using optical-flow alone.

The objective of this prototype is to demonstrate that a full-fledged camera-based ADAS can be implemented using MATLAB or other programming tools. We claim that all the required technologies for implementing a full-fledged camera-based ADAS are available now. However, as mentioned before, the full-fledged implementation, testing and performance evaluation of the proposed system shall be done in the next phase of this project.

Strengths and weaknesses

Our proposed design of the system has a number of strong points.

1. It provides ADAS functions mainly based on five cameras. Many innovations are being introduced in cameras every day. For examples, infrared enabled cameras can see at night as well; cameras with microphone can listen as well; and radar-enabled cameras can generate 3D pictures of the environment (Johnson 2006). These innovative cameras will soon become cheaper like an ordinary camera. In addition, we have seen many inno-

Fig. 21 On-road object recognition in the input frame. **a** Pedestrian detection, **b** vehicle detection, **c** road sign detection, **d** lane-marking detection

vative applications of a camera in the last few decades. Having installed cameras on a vehicle opens doors to many innovative applications to come in the future.

2. The cost of a camera-based ADAS is much lower than other technologies because the price of a CMOS camera is only a few dollars, starting from US$ 15 for ordinary camera and US$ 20 for an infrared-enable camera. The popularity of cameras in mobile phones and other handheld devices has encouraged producers to design cheaper, smaller and efficient cameras.
3. Camera-based ADAS had poor performance until few years ago. However, camera technology has significantly improved nowadays which makes it possible to design high performance automotive functions.
4. A camera-based ADAS does not depend on any infrastructure outside the vehicle. For example, lane departure warning can work even if there are no visible lane markings on the road or magnetic markers embedded. Additionally, it can be used with new as well as old vehicles having no support for infrastructure.
5. A camera-based ADAS is very simple to implement i.e. to develop, install and maintain. This is because the area of video and image processing has been around us for decades; and the proposed algorithms are much accurate and faster now. These algorithms, with slight modifications, can be used in the development of camera-based ADAS. Today, a large number of camera-based techniques are available for detecting the speed, distance, relative position, direction of movement, and size and type of objects on the road.
6. A camera-based ADAS is more intelligent than a system based on radar, sonar or lidar. It can distinguish between the relevant traffic from irrelevant things such as obstacles and tin cans. It is also possible to incorporate learning and prediction capability using techniques such as scene analysis. Moreover, a camera-based system can host multiple applications and has ability to integrate with other systems as well.
7. The camera-based ADAS has very high availability. It uses cameras, processor, and a display. The CMOS cameras are readily available in the market and are very easy to install and operate. Similarly, processors and displays are also easily available at lower costs.
8. A camera-based system can easily be integrated with other systems. However, this integration becomes smoother and easier if all components are camera-based. For example, a camera-based lane departure warning system can be integrated with traffic sign recognition system to share the same camera between them.
9. The capabilities of a CMOS camera can be increased by fusing some other kind of sensing into it. For example, radar-enabled CMOS camera can also find speed and direction of every object in a scene at once using time-of-flight calculations on each pixel (Johnson 2006).

10. Finally, a camera can scan much wider area as compared to other technologies. For example, radar has a very limited field-of-view (about 16°), whereas a normal camera has 46° field-of-view and a wide-angle camera has a field-of-view as wider as 180°. Moreover, a camera faces no interference from absorbents like a radar or sonar. However, it is interfered by lighting conditions, such as reflections, like a lidar. Poor lighting, bad weather, and high illuminations etc also affect its performance. Nowadays, to overcome these issues, we have cameras with wide dynamic range—WDR (Hertel et al. 2008) of more than 120 dB that can handle both bright and dark environments by automatic adjustments (see Fig. 23).

Although the proposed system is designed very carefully, it has many weaknesses. Some of these weaknesses are inherited from the technology while others are inherited from design itself.

1. The performance of proposed system is affected by the bad weather conditions such as fog, dust, rain, and particularly snow. This is because the visibility is severely reduced during bad weather. However, infrared-enabled or radar-enabled cameras will remove this weakness in the future.
2. The proposed system has lower accuracy of speed and distance measurements when compared to radar, sonar or lidar. This is because a camera cannot accurately measure the speed and distance of an object if it is too slow or too close to the camera. Again, infrared-enabled or radar-enabled cameras will improve accuracy of the measurements.
3. The proposed system uses LCD display to show reconstructed environment. It is important to note that a driver can pay only a little attention to the displayed information while driving. A driver may be distracted while looking at the display for more than a few seconds. To avoid this problem, we can use a projector for head-up-display (HUD), but it will significantly increase the cost of our proposed system.
4. As the proposed system uses five cameras, the issue of privacy cannot be overlooked. A camera inside the vehicle might be invasive for driver, and the cameras outside the vehicle might be invasive for neighboring travelers on the road. Furthermore, the possibility of adding new applications into the system can make it possible to record every movement of the neighbors.
5. Finally, the proposed system requires some tuning in the beginning (at the time of installation only) because the camera parameters should be determined for accurate measurements of speed and distance.

Fig. 22 Detection of all neighboring objects at the same time

Conclusions and future work

Aiming at development of vision-based ADAS, we carried out an ethnographic study of how people drove their vehicles, observed their activities while they drove, engaged them in discussions, and used questionnaires to get feedback. We can conclude our findings as follows.

First, it would be very useful for drivers to avoid accidents if they are provided with the information on speed,

(a) (b) (c)

Fig. 23 Imaging without (**a**) & with (**b**, **c**) wide dynamic range—WDR (Hertel et al. 2008). **a** Image captured without WDR (things not very clear), **b** image captured with WDR (everything very clear), **c** a night scene captured with WDR (everything very clear even at night) distance, relative position, direction, and size and type of the vehicles or other objects around them. These five pieces of information are enough to build a full-fledged camera-based ADAS and can be captured using different technologies. A large number of camera-based techniques were described for obtaining the required information. We did a survey of all the supporting technologies including radar, sonar, lidar, GPS, and video-based analysis, and found that video-based analysis is the most suitable technology for this purpose because it provides all the required support for implementing ADAS functions in a simple way and at a very low-cost. Depending on the power of digital image processor, more than 30 frames can be processed in one second for automotive applications.

Second, for the presentation of information to the drivers in a distraction-free way, we process this information to reconstruct the environment and draw the birds'-eye view on a display mounted on the dashboard, behind the steering, and just in front of the driver.

Third, to ensure simple and easy user interface, we make our system context-aware and hence adaptive. It requires minimal input from the users, but gives maximum control over the system. The proposed system uses a touch-screen display and issues only audio-visual alerts to make the interaction simple and easy for drivers.

Finally, we have proposed a vision-based ADAS that uses layered architecture of context-aware systems. We have given the design of twelve most common ADAS functions using only video-based analysis. We have also demonstrated a basic prototype using MATLAB to show how fast and easy it is to implement any camera-based ADAS function.

Since we spent limited time and resources on this project, many deficiencies are present in it. Therefore, a number of future enhancements are possible in the system.

First, we have described the design of all ADAS functions for proposed system. However, our prototype implements only few of them. We plan to implement all the proposed functions in future as a full-fledged integrated ADAS system.

Second, the proposed system does not learn from user actions presently. However, we can incorporate learning in its future version.

Third, with few enhancements, the proposed system is useable for training a new driver. This requires some more functions in order to advise a new driver and control the vehicle in case of emergency.

Finally, camera-based automotive systems are still in the development phase and will take few more years to have reliable applications for automobiles. Recently, infrared-enabled and radar-enabled CMOS cameras with high accuracy and reliability are available. Fusing radar and vision sensing will make the proposed system very much accurate and reliable in the future.

References

Abuelela, M., Olariu, S., & Weigle, M. C. (2008). NOTICE: An architecture for the notification of traffic incidents. In *Vehicular technology conference, 2008. VTC Spring 2008. IEEE* (pp. 3001–3005).

Adell, E., Varhelyi, A., Alonso, M., & Plaza, J. (2008). Developing human-machine interaction components for a driver assistance system for safe speed and safe distance. *IET Intelligent Transport Systems, 2*(1), 1–14.

Akhlaq, M. (2010). *A smart-dashboard: Augmenting safe & smooth driving*. Master thesis no. 2010:MUC:01, School of Computing, Blekinge Institute of Technology (BTH), Ronneby, Sweden.

Albu, A. B., Widsten, B., Wang, T., Lan, J., & Mah, J. (2008). A computer vision-based system for real-time detection of sleep onset in fatigued drivers. *Intelligent vehicles symposium, 2008 IEEE* (pp. 25–30).

Andrade, L. C. G., Campos, M. F. M., & Carceroni, R. L. (2004). A video-based support system for nighttime navigation in semi-structured environments. In *Computer graphics and image processing, XVII Brazilian symposium on (SIBGRAPI'04)* (pp. 178–185).

Baldauf, M., Dustdar, S., & Rosenberg, F. (2007). A Survey on Context-Aware Systems. *International Journal of Ad Hoc and Ubiquitous Computing, 2*(4), 263–277.

Bergasa, L. M., Nuevo, J., Sotelo, M. A., Barea, R., & Lopez, M. E. (2006). Real-time system for monitoring driver vigilance. *Intelligent Transportation Systems, IEEE Transactions On, 7*(1), 63–77.

Bergmeier, U. (2008). Augmented reality in vehicle0—technical realisation of a contact analogue Head-up Display under automotive capable aspects; usefulness exemplified through Night Vision Systems. In *Proceedings of 32. World Automotive Congress, 2008*.

Bertozzi, M., Broggi, A., & Fascioli, A. (1998). Stereo inverse perspective mapping: Theory and applications. *Image and Vision Computing, 8*(16), 585–590.

Brauckmann, M. E., Goerick, C., Groß, J., & Zielke, T. (1994). Towards all around automatic visual obstacles sensing for cars. In *Proceedinhs of intelligent vehicle symposium* (pp. 79–84).

Cao, X. B., Qiao, H., & Keane, J. (2008). A low-cost pedestrian-detection system with a single optical camera. *Intelligent Transportation Systems, IEEE Transactions On, 9*(1), 58–67.

Cheng, H., Liu, Z., Zheng, N., & Yang, J. (2007). Enhancing a Driver's situation awareness using a global view map. In *Multimedia and expo, 2007 IEEE international conference on,* (pp. 1019–1022).

Computer Visio System Toolbox. (2011). *Video and image processing blockset 2.8*. http://www.mathworks.com/products/viprocessing/demos.html. Accessed 22 June 2011.

David, M. (2006). ESC gives life to smart fabric, smart dashboard. *Electronic Design, 54*(9), 19–19.

Delot, T., Ilarri, S., Cenerario, N., & Hien, T. (2011). Event sharing in vehicular networks using geographic vectors and maps. *Mobile Information Systems, 7*(1), 21–44.

Devi, M. S., & Bajaj, P. R. (2008). Driver fatigue detection based on eye tracking. Emerging trends in engineering and technology, 2008. In *ICETET '08. First international conference on* (pp. 649–652).

Ehlgen, T., & Pajdla, T. (2007). Monitoring surrounding areas of truck-trailer combinations. In: *Proceedings of the 5th international conference on computer vision systems, Bielefeld, Germany.*

Ehlgen, T., Thorn, M., & Glaser, M. (2007). Omnidirectional cameras as backing-up aid. Computer vision, 2007. ICCV 2007. In *IEEE 11th International Conference on* (pp. 1–5).

Eriksson, J., Girod, L., Hull, B., Newton, R., Madden, S., & Balakrishnan, H. (2008). The pothole patrol: Using a mobile sensor network for road surface monitoring. In *Proceedings of the 6th* *international conference on mobile systems, applications, and services (Breckenridge, CO, USA, June 17–20, 2008). MobiSys '08* (pp. 29–39). ACM, New York, NY.

Finnefrock, M., Jiang, X., & Motai, Y. (2005). Visual-based assistance for electric vehicle driving. *Intelligent vehicles symposium, 2005. Proceedings. IEEE,* (pp. 656–661).

Fletcher, L., Petersson, L., & Zelinsky, A. (2003). Driver assistance systems based on vision in and out of vehicles. In *Proceedings of IEEE intelligent vehicles symposium* (pp. 322–327).

Franke, U., & Kutzbach, I. (1996). Fast stereo based object detection for stop and go traffic. In *Proceedings of intelligent vehicles symposium* (pp. 339–344).

Fritsch, J. , Michalke, T., Gepperth, A., Bone, S., Waibel, F., Kleinehagenbrock, M., et al. (2008). Towards a human-like vision system for driver assistance. In *IEEE intelligent vehicles symposium*. Eindhoven University of Technology, Eindhoven, The Netherlands.

Future Launches by Mobileye. (2010). http://www.mobileye.com/manufacturer-products/product-launches/future. Accessed 22 June 2011.

Giachetti, A., Campani, M., & Torre, V. (1998). The use of optical flow for road navigation. *IEEE Transactions on Robotics and Automation, 14*(1), 34–48.

Handmann, U., Kalinke, T., Tzomakas, C., Werner, M., & Seelen, W. V. (2000). An image processing system for driver assistance. *Image and Vision Computing, 18*(5), 367–376.

Hertel, D., Betts, A., Hicks, R., & ten Brinke, M., (2008). An adaptive multiple-reset CMOS wide dynamic range imager for automotive vision applications. *Intelligent vehicles symposium, 2008 IEEE* (pp. 614–619).

Hoffmann, C., Dang, T., & Stiller, C. (2004). Vehicle detection fusing 2D visual features. *IEEE intelligent vehicles symposium* (pp. 280–285).

Hull, B., Bychkovsky, V., Zhang, Y., Chen, K., Goraczko, M., Shih, E., et al. (2006). CarTel: A distributed mobile sensor computing system. In *Proceedings of the 4th ACM SenSys*.

Ichihara, E., & Ohta, Y., (2000). NaviView: Visual assistance using roadside cameras—evaluation of virtual views. In *Proceedings of intelligent transportation system conference* (pp. 322–327).

JISC Digital Media. (2011). Digital cameras. 18 May 2009. http://www.jiscdigitalmedia.ac.uk/stillimages/advice/digital-cameras/. Accessed 22 June 2011.

Johnson, R. C. (2006). *CMOS imager chips enable true machine vision*. Dec. 19, 2006. http://www.eetasia.com/ART_8800446742_480500_NP_89a21a9f.HTM. Accessed 22 June 2011.

Jonefjäll, M. (2009). *Visual assistance HMI for use of video camera applications in the car*. ISSN 1402-1617/ISRN LTU-EX-09/003-SE / NR 2009:003, Master's thesis, Luleå University of Technology, Sweden.

Kanevsky, D. (2008). *Telematics: Artificial passenger and beyond. Human factors and voice interactive systems* (pp. 291–325). New York: Springer.

Kim, S., Kang, J., Oh, S., Ryu, Y., Kim, K., Park, S., et al. (2008). An intelligent and integrated driver assistance system for increased safety and convenience based on all-around sensing. *Journal of Intelligent and Robotics System, 51*(3), 261–287.

Kircher, A., Uddman, M., & Sandin, J. (2002). *Vehicle control and drowsiness*. Swedish National Road and Transport Research Institute, Linkoping, Sweden, Tech. Rep. VTI-922A.

Knipling, R. (2000). Changing driver behavior with on-board safety monitoring. *ITS Quarterly, VIII*(2), 27–35.

Kumar, M., & Kim, T. (2005). Dynamic speedometer: Dashboard redesign to discourage drivers from speeding. In *CHI '05 extended abstracts on human factors in computing systems (Portland, OR, USA, April 02–07, 2005). CHI '05* (pp. 1573–1576). ACM, New York, NY.

Li, Y., Yin, L., Jia, Y., & Wang, M. (2008). Vehicle speed measurement based on video images. In *3rd international conference on innovative computing information and control, ICICIC* (p. 439).

Lim, K. H., Ang, L. M., Seng, K. P., & Chin, S. W. (2009). Lane-vehicle detection and tracking. In *Proceedings of the international multiconference of engineers and computer scientists 2009 Vol II IMECS 2009, Hong Kong*.

Lin, H., Li, K., & Chang, C. (2008). Vehicle speed detection from a single motion blurred image. *Image and Vision Computing 26*(10), 1327–1337.

Liu, J., Su, Y., Ko, M., & Yu, P. (2008a). Development of a vision-based driver assistance system with lane departure warning and forward collision warning functions. In *Proceedings of the 2008 digital image computing: Techniques and applications (December 01–03, 2008). DICTA* (pp. 480–485). Washington, DC: IEEE Computer Society.

Liu, Y. C., Lin, K. Y., & Chen, Y. S. (2008b). Bird's-eye view vision system for vehicle surrounding monitoring. In *Proceedings of the conferene on robot vision* (pp. 207–218). Berlin, Germany, Feb. 20, 2008.

Lotan, T., & Toledo, T. (2005). Evaluating the safety implications and benefits of an in-vehicle data recorder to young drivers. In *Proceedings of the third international driving symposium on human factors in driver assessment, training and vehicle design*. Maine, USA, June 27–30, 2005.

Martinez, E., Diaz, M., Melenchon, J., Montero, J. A., Iriondo, I., & Socoro, J. C. (2008). Driving assistance system based on the detection of head-on collisions. In *Intelligent vehicles symposium, 2008 IEEE* (pp. 913–918). 4–6 June, 2008.

McCall, J. C., & Trivedi, M. M. (2006). Video-based lane estimation and tracking for driver assistance: Survey, system, and evaluation. *IEEE Transactions on ITS, 7*(1), 20–37.

Mohan, P., Padmanabhan, V. N., & Ramjee, R. (2008). Trafficsense: Rich monitoring of road and traffic conditions using mobile smartphones. In *Proceedings of the conference on embedded networked Sensor Systems (SenSys)* (pp. 323–336).

Nakamura, Y. (2008). JAMA Guideline for In-Vehicle Display Systems. HMI Experts Group, JAMA, (Honda R&D Co., Ltd.). Document No: 2008-21-0003, October 2008. http://www.sae.org/technical/papers/2008-21-0003. Accessed 22 June 2011.

Nashashibi, F., Khammari, A., & Laurgeau, C. (2008). Vehicle recognition and tracking using a generic multisensor and multialgorithm fusion approach. *International Journal of Vehicle Autonomous Systems, 6*(1–2), 134–154.

Nedevschi, S., Danescu, R., Marita, T., Oniga, F., Pocol, C., Sobol, S., et al. (2007). A sensor for urban driving assistance systems based on dense stereovision. In *Intelligent vehicles symposium, 2007 IEEE* (pp. 276–283). 13–15 June, 2007.

Nookala, M., & Estochen, B. (2002). Minnesota, USA intelligent vehicle initiative. In *Intelligent vehicle symposium, 2002. IEEE* (vol. 2, pp. 533–536). 17–21 June 2002.

Oki, Y., Yamada, F., Seki, Y., Mizutani, H., & Makino,H. (2003). Actual road verification of AHS support system for prevention of vehicle overshooting on curves. In Proceedings of the 2nd ITS Symposium 2003 (pp. 247–252).

Peden, M., Scurfield, R., et al., eds. (2004). World report on road traffic injury prevention. World Health Organization, Geneva. http://www.who.int/violence_injury_prevention/publications/road_traffic/world_report/en/index.html. Accessed 22 June 2011.

Perrillo, K. V. (1997). *Effectiveness of speed trailer on low-speed urban roadway*. Master Thesis, Texas A&M University, College Station, TX.

Piccioli, G., De Micheli, E., Parodi, P., & Campani, M. (1996). Robust method for road sign detection and recognition. *Image and Vision Computing, 14*(3), 209–223.

Porcino, D. (2001). Location of third generation mobile devices: A comparison between terrestrial and satellite positioning systems. In *Vehicular technology conference, 200, VTC 2001 Spring. IEEE VTS 53rd* (Vol. 4, pp. 2970–2974).

Pugh, S. (2008). The Train Operator's view. The Institution of Engineering and Technology Seminar on User Worked Crossings, Birmingham (pp. 103–112). 30–30 Jan. 2008.

Qadri, N. N., Altaf, M., Fleury, M., & Ghanbari, M. (2010). Robust video communication over an urban VANET. *Mobile Information Systems, 6*(3), 259–280.

Raghavan, S., Yang, C. Z., Jovanis, P. P., Kitamura, R., Owens, G., & Anwar, M. (1992). California Advanced Driver Information System (CADIS). Final Report. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-92-20, December, 1992, pp. 214.

Rakotonirainy, A., Feller, F., & Narelle, L. (2008). Using in-vehicle avatars to prevent road violence. Centre for Accident Research and Road Safety (CARRS-Q). http://pervasive2008.org/Papers/LBR/lbr17.pdf. Accessed 22 June 2011.

Reding, V., (2006). The intelligent car initiative: Raising awareness of ICT for smarter, safer and cleaner vehicle. Speech delivered at the Intelligent Car Launching Event, vol. 23, Brussels, Belgium. http://eur-lex.europa.eu/smartapi/cgi/sga_doc?smartapi!celexplus!prod!DocNumber&lg=en&type_doc=COMfinal&an_doc=2006&nu_doc=59. Accessed 22 June 2011.

Ross, M., Francis, M., Jill, H., Mark, F., Michael, S., Tracey, R., et al. (2008). Co-Driver Alert project. Road Transport Information and Control—RTIC 2008 and ITS United Kingdom Members' Conference, IET , vol., no., pp. 1–6, 20–22 May 2008.

Santos, J., Merat, N., Mouta, S., Brookhuis, K., & De Waard, D. (2005) The interaction between driving and in-vehicle information systems: Comparison of results from laboratory, simulator and real-world studies. *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(2), 135–146

Sato, Y., & Makanae, K., (2006). Development and evaluation of in-vehicle signing system utilizing RFID tags as Digital Traffic signs. *International Journal of ITS Research*, Vol. 4, No.1, December 2006.

Shibata, M., Makino, T., & Ito, M. (2008). Target distance measurement based on camera moving direction estimated with optical flow. In *10th IEEE international workshop on advanced motion control, AMC '08*, Trento (pp. 62–67). 26–28 March 2008.

Smith, P., Shah, M., & Lobo, N. V. (2003). Determining driver visual attention with one camera. *IEEE Transactions On Intelligent Transportation Systems*, Vol. 4, No. 4, December 2003.

Spaho, E., Barolli, L., Mino, G., Xhafa, F., Kolici, V., & Miho, R. (2010). Implementation of CAVENET and its usage for performance evaluation of AODV, OLSR and DYMO protocols in vehicular networks. *Mobile Information Systems, 6*(3), 213–227.

Spelt, P. F., Tufano, D. R., & Knee, H. E. (1997). Development and evaluation of an in-vehicle information system. In *Proceedings of the seventh annual meeting and exposition of the intelligent transportation society of America* Washington, D.C. June 2–5, 1997.

Stein, G. P., Mano, O., & Shashua, A. (2003). Vision-based ACC with a single camera: Bounds on range and range rate accuracy. In *Intelligent vehicles symposium, 2003. Proceedings. IEEE*, (pp. 120–125). 9–11 June 2003.

Su, C. Y., & Fan, G. H. (2008). An effective and fast lane detection algorithm. Lecture Notes in Computer Science (Vol. 5359/2008, pp. 942–948). Berlin/Heidelberg: Springer.

Torralba, A. (2003). Contextual priming for object detection. *International Journal of Computer Vision, 53*(2), 169–191.

Toyota, K., Fuji, T., Kimoto, T., & Tanimoto, M. (2000). A proposal of HIR (Human-Oriented Image Restructuring) Systems for ITS. In *Proceedings of the intelligent vehicle symposium* (pp. 540–544).

Treat, J. R., Tumbas, N. S., McDonald, S. T., Shinar, D., Hume, R. D., Mayer, R. E., et al. (1977). Tri-level study of the causes of traffic accidents. Report No. DOT-HS-034-3-535-77, Indiana University.

Trivedi, M. M., Gandhi, T., & McCall, J. (2007). Looking-in and looking-out of a vehicle: Computer-vision-based enhanced vehicle safety. *Intelligent Transportation Systems. IEEE Transactions On, 8*(1), 108–120.

US Department of Transportation (2004). Volume I: Guidelines,. In-Vehicle Display Icons and Other Information Elements. Publication NO. FHWA-RD-03-065 September 2004. http://www.tfhrc.gov/safety/pubs/03065/03065.pdf. Accessed 22 June 2011.

US Department of Transportation. (1996). Development of Human Factors Guidelines for Advanced Traveler Information Systems and Commercial Vehicle Operations: Comparable Systems Analysis. Publication Number: FHWA-RD-95-197, December 1996, http://www.fhwa.dot.gov/tfhrc/safety/pubs/95197/. Accessed 22 June 2011.

Vashitz, G., Shinar, D., & Blum, Y. (2008). In-vehicle information systems to improve traffic safety in road tunnels. *Transportation Research Part F: Traffic Psychology and Behaviour, 11*(1), 61–74.

Walker, J. G., Barnes, N., & Anstey, K. (2006). Sign detection and driving competency for older drivers with impaired vision. In B. MacDonald (Ed.), *Proceedings of the 2006 Australasian conference on robotics & automation* Auckland, New Zealand, December 6–8, 2006.

Wang, C.-C., Chen, C.-J., Chan, Y.-M., Fu, L.-C., & Hsiao, P.-Y. (2006). Lane detection and vehicle recognition for driver assistance system at daytime and nighttime. *Image and Recognition Magazine, 12*(2), 4–17.

Wilcox, D. (1999). Mercedes moves into mechatronic overdrive. *Transport Engineer*, pp. 21–30. Aug. 1999.

Woll, J. D. (1995). VORAD collision warning radar. In *Radar conference, 1995., Record of the IEEE 1995 International* (pp. 369–372). 8–11 May 1995.

Xuan, K., Zhao, G., Taniar, D., Safar, M., & Srinivasan, B. (2011a). Voronoi-based multi-level range search in mobile navigation. *Multimedia Tools Applications, 53*(2), 459–479.

Xuan, K., Zhao, G., Taniar, D., Safar, M., & Srinivasan, B. (2011b). Constrained range search query processing on road networks. *Concurrency and Computation: Practice and Experience, 23*(5), 491–504.

Xuan, K., Zhao, G., Taniar, D., & Srinivasan, B. (2008a). Continuous range search query processing in mobile navigation. In *Proceedings of the 14th international conference on parallel and distributed systems (ICPADS 2008), IEEE* (pp. 361–368).

Xuan, K., Zhao, G., Taniar, D., & Srinivasan, B. (2008b). Incremental k-nearest-neighbor search on road networks. *Journal of Interconnection Networks, 9*(4), 455–470.

Yoo, S., Chong, P. K., Park, T., Kim, Y., Kim, D., Shin, C., et al. (2008). DGS: Driving guidance system based on wireless sensor network. In *Advanced information networking and applications—Workshops, 2008. AINAW 2008. 22nd International conference on* (pp. 628–633), 25–28 March 2008.

Zhao G., Xuan K., Rahayu W., Taniar D., Safar M., Gavrilova M., et al. (2010). Voronoi-based continuous k nearest neighbor search in mobile navigation. *IEEE Transactions on Industrial Electronics 58*(6), 2247–2257

Zhu, Y., Comanicciu, D., Ramesh, V., et al. (2005). An integrated framework of vision-based vehicle detection with knowledge fusion. In *Proceedings of the intelligent vehicle Symposium* (pp. 199–204).

Zin, T. T., Koh, S. S., & Hama, H. (2007). Robust signboard recognition for vision-based navigation. *The Journal of The Institute of Image Information and Television Engineers, 61*(8), 1192–1200.

Zoratti, P. (2011). FPGAS provide platform for driver assistance. Electronic Product Design Magazine. 28 April 2011. http://www.epdonthenet.net/article/41913/FPGAS-provide-platform-for-driver-assistance.aspx. Accessed 22 June 2011.