Collision avoidance technology: from parking sensors to unmanned aircraft

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Abstract
Purpose – To examine the sensors and techniques used in preventing the collision of moving vehicles.
Design/methodology/approach – A review of automobile-guidance research projects carried out in European universities and advanced safety vehicle development by Japanese car manufacturers is followed by a description of driver assistance systems in current use. A new research initiative for autonomous unmanned aircraft is then discussed.
Findings – Fully-autonomous prototype vehicles have demonstrated impressive feats on public roads, but car manufacturers are currently concentrating on driver assistance systems. Research is underway to extend the use of unmanned aircraft into the civil field, and to allow them to share airspace with piloted planes.
Originality/value – Presents current policies in automotive and aerospace development, and describes the range of sensor technologies applied to collision avoidance.

Keywords Road vehicles, Image sensors, Sensors, Accident prevention

Paper type Technical paper

Introduction

For reasons of safety, convenience and improved traffic flow, there has been a drive to develop autonomous road vehicles. In Europe, such a project was launched in the mid-1980s, and Japan started its advanced safety vehicle (ASV) project in 1991. Various technologies are involved, including vision systems, radar, inertial heading sensors, inter-vehicle communications, and global positioning systems (GPS). Some of the test vehicles have demonstrated fully autonomous performance on real roads, but the current trend is to provide driver assistance rather than true autonomy. This currently takes the form of parking sensors, adaptive cruise control ACC, night vision aids, radar and imaging collision warning systems, and inter-vehicle communications systems that detect vehicles not yet in sight.

Aircraft are routinely equipped with pilot assistance instruments such as navigational aids, autopilot and collision warning devices. Unmanned aircraft carry out surveillance missions under ground control, and there is a move afoot to make them capable of autonomous collision avoidance, with the aim of sharing airspace with piloted aeroplanes.

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Academic and industrial automotive research

Since, 1997, the IEEE Intelligent Transportation Systems Society has held an annual conference to draw together researchers in industry and academia to discuss all aspects of vehicle-related intelligent systems, including automated vehicles and driver assistance systems, collision avoidance and driver attention monitoring. It sponsored the Intelligent Vehicles Symposium on 19 and 20 September 2006 in Tokyo, Japan, which included papers on the use of sensors such as optical spread spectrum radar, millimetre wave radar, optical imaging including stereopsis, magnetic sensors, heading sensors, and infrared radiation for inter-vehicle communication; and software algorithms including image processing, model-based neural distance control, tangent-based curve negotiation, platoon-formation algorithms and positional servoing within platoons, and self-tuning fuzzy logic controllers.

One of the papers described a vision-based control system developed at the Universität der Bundeswehr that detects objects, tracks the road and automatically avoids collisions. The original system used a single monochromatic camera and achieved fast image processing by concentrating on particular regions of interest. It was mounted in a 5 ton van called VaMoRs, which it controlled at speeds of up to 130 km/h. In a long distance test ride from Munich to Odense in Denmark and back in November 1995, the vehicle covered over 1,600 km autonomously. The system was developed under a European research programme called PROMETHEUS, launched in 1986 by the automotive industry to reduce accidents and improve traffic flow.

The system has more recently been implemented in a Mercedes S class car, the VaMP, and uses bifocal vision and a cycle time of 40 m to give real-time manoeuvring capability.

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Recursive estimation procedures are used. Three or four TV cameras on a tilt-and-yaw platform give a wide field of view with central overlap for high resolution and stereo interpretation. They provide binocular vision at ranges up to 10 m to detect vehicles "cutting in" and monocular distance estimation with motion stereo for the longer range forward view. Active gaze control allows the cameras to turn to follow the road in tight bends, and compensate for angular perturbations caused by rough ground. Orthonormal accelerometers and rate sensors give inertial stabilisation of the viewing direction. A third-generation development called expectation-based multi-focal saccadic (EMS) vision processing Dickmanns (2003) is performed by dual-processor PCs and additional microprocessors. The human vision system explores a scene by discontinuous movements (saccades) to different points of interest. Saccadic vision is a way of selecting information relevant to the task in hand. A knowledge-base of stereotypical manoeuvres of different objects (such as pedestrians and cars) helps the system anticipate movement from frame to frame and reduce the necessary processing. By broadening the field of view and extending applicability to rough road surfaces, the Universität der Bundeswehr system is developing a complex but robust vision system for ground vehicles.

Another system developed under PROMETHEUS is the Generic Obstacle and Lane detection (GOLD) system from the Università di Parma, Italy. This uses inverse perspective mapping parallel stereo vision, and the ARGO vehicle to which it was attached (Figure 1) carried out a 6-day 1,000-mile tour of Italian motorways, driving autonomously 94 per cent of the time. In automatic mode it follows the lane, localises objects in its path and can change lanes. It worked well on flat roads with gentle curves. Two synchronised monochromatic cameras with 360 line resolution are positioned at the top corners of the windscreen, and the images are acquired by a framegrabber at 25 full frames per second and stored in a computer. The standard 200 MHz MMX Pentium processor analyses the images to find the position of obstacles and the geometry of the road, and drives an actuator on the steering wheel. The lane detection system requires a flat road with clear markings. The processing detects the distance, speed and direction of the vehicle in front by finding a rectangular bounding box in a specific region of the image.

A camera on a moving vehicle captures images that change with time, due to the progress of the vehicle and any bumps and twists on the road. The Bundeswehr system uses its EMS system to pick out objects of interest, track them from image to image and extrapolate their expected position. The GOLD system uses inverse perspective mapping to remove the changing perspective effect from the images. An up-to-date review of the development of unmanned ground vehicles (UGVs) is given in Bertozzi *et al.* (2006).

Another system that has been tested in real highway conditions is the Car Collision Avoidance System from the Module research centre in Russia in partnership with GosNIIAS aviation research centre. This uses binocular vision processing with Kalman filtration, processing in real time. It can extrapolate a lane in the absence of markings and track multiple vehicles in front.

A number of car manufacturers are developing ASVs to improve safety. The project was launched in 1991 by the Japanese Ministry of Land, Infrastructure and Transport, and the third phase of the project was completed in 2005. For example, the Honda ASV-3 (Figure 2) uses cameras and millimetre-wave radar to detect obstacles and approaching vehicles and assists in steering and braking, and communicates positional information with other vehicles. A rear-mounted camera helps a driver change lanes safely. The inter-vehicle communication system uses 5.8 GHz two-way radio signals to detect approaching vehicles to help determine whether it is safe to proceed at an intersection, and to warn of vehicles approaching at a blind corner. It is even proposed that pedestrians carry portable transmitters to warn drivers of their presence. These systems aim to supply extra information to support drivers' decision-making processes, by audio, visual and tactile warnings. An example of a tactile warning is vibrating the pedals or applying torque to the steering wheel. The vehicle also carries a GPS antenna and automatically communicates its position to the Honda Operations Centre if involved in an accident. The motorbike version of the Honda ASV-3 (Figure 3) uses a Bluetooth communications helmet and the vehicle itself has a frontal design imitating a face, because the human vision system is particularly sensitive to faces so this improves the motorbike's visibility.

Mitsubishi's Active Safety ASV incorporates two lane-detecting cameras, two scanning laser radar systems, six passive trigonometric-type sensors, and three stereo cameras, to detect surrounding traffic situations. It has a collision avoidance system that warns the driver and carries out automatic collision avoidance if necessary.

Current automotive systems

Some basic collision avoidance systems such as parking sensors and radar-assisted ACC are now fitted as standard in many cars, or available for retrofitting. Infrared vision systems are becoming available to assist night-time driving.

ParkingSensors.co.uk is a direct-selling online supplier, established in 1997, which sells and gives independent advice on a range of parking sensors. Ultrasonic sensors are the most widely used at present, and manufacturers include Veba and Nikkai. They send and receive ultrasonic waves that reflect from any nearby obstacles, the time of flight giving a measure of distance. For example, the Veba AVRS1 costs £49.99 and has four ultrasonic sensors that fit on the bumper, a warning buzzer that gives bleeps of increasing frequency as the obstacle is approached. A digital display simultaneously shows the distance in cm to the nearest object. The AVRS4, at £199.99, also has a camera and 5-in. monitor.

Laver Technology is an electronics manufacturing company that designs, develops and manufactures in house, and makes parking systems for cars and commercial vehicles. The UltraPark 2000-S (rear detection) and 2000SF (front detection) emit a focused flat beam of ultrasonic radiation and detect reflections from objects as small as a broom handle. The company supplies customised systems to individuals and garages, and claims that the flat beam is better than the standard ultrasonic funnel shape and can cover the full width of the vehicle, or beyond.

There are also electromagnetic devices such as Taurus. A strip antenna generates an electromagnetic field and detects changes in it, relying on the vehicle's movement to generate the change signal. The Taurus T123 at £79.99 mounts

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Figure 1 The interior of the ARGO autonomous vehicle has cameras at the top left and top right of the windscreen and an image monitor, and a motor to control the steering wheel

invisibly inside the bumper and its operation is unaffected by spare tyres and tow bars. It gives three different sounds as an obstacle is approached: a slow beep 50-80 cm away, a faster beep 25-50 cm, and a continuous tone closer than 25 cm. It can detect smaller objects than the ultrasonic devices, and is maintenance free. Proxel makes the EPS electromagnetic parking sensor, and it is one of the standard accessories for Fiat. It senses along full length of bumper, giving no blind spots. The first model, EPS-2 came out in 1994. The more recent EPS-micro plus has a memory of the obstacle. This technology can detect obstacles at short range, closer than 12 in., an advantage over ultrasonics.

Laser Protector Ltd makes an infrared parking aid called the Laser PRO-PARK operating at 904 nm wavelength. A single laser sensor is fitted to either the front or the rear of the vehicle, and additional laser sensor heads can be supplied to plug into the same junction box.

Standard cruise control systems control the throttle to maintain the speed set by the driver. ACC systems augment this with forward-looking radar to monitor the distance from the vehicle in front, and alter the speed to maintain a safe distance. Autocruise is a subsidiary of TRW, and its ACC radar operates at 77 GHz. Delphi Electronics' system uses 76 GHz, and both have a range of 150 m. The ACC system developed by General Motors and Delphi Electronics presents visual warnings to the driver on a head-up display, and if necessary applies braking of up to 0.3 G.

Figure 2 The Honda ASV-3 uses cameras and radar to detect obstacles and approaching vehicles and assists in steering and braking

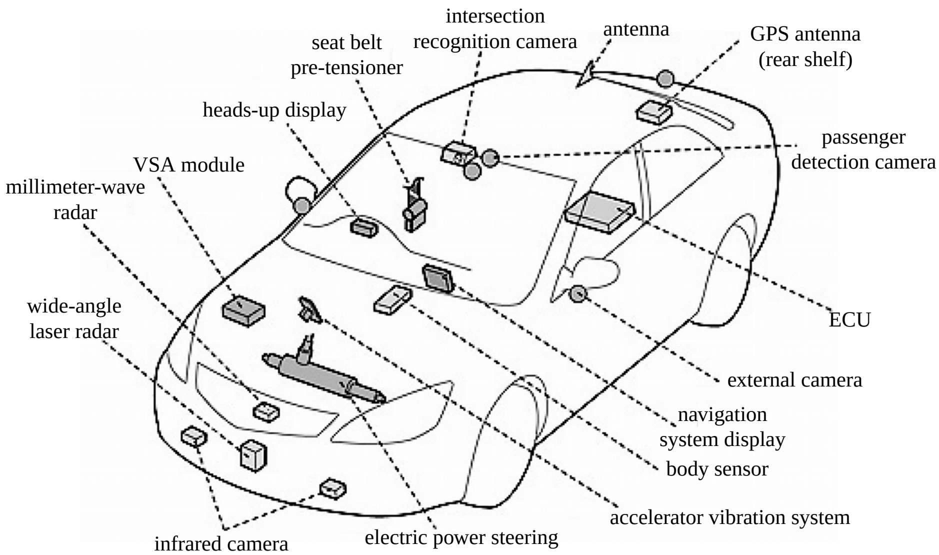
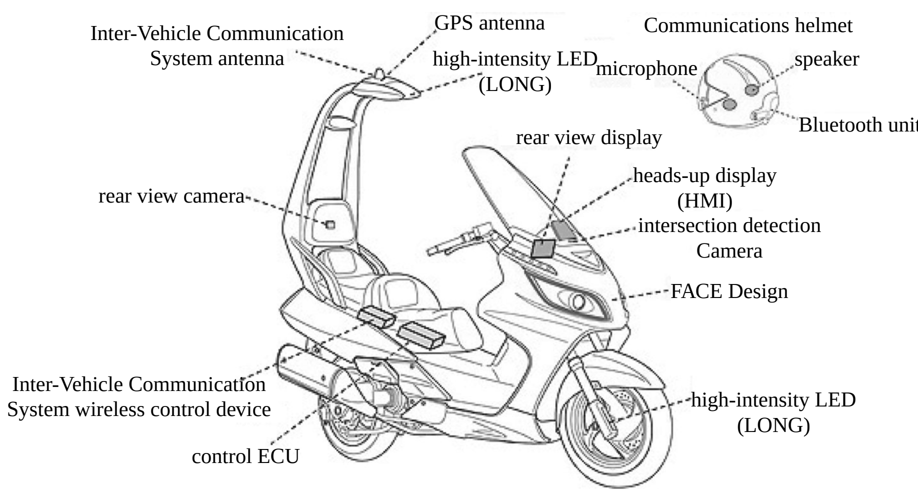


Figure 3 The Honda motorbike ASV incorporates a range of sensors and its front presents a face design to make it immediately visible to other drivers



Nissan's distance control assist system claims to be very useful in heavy traffic requiring frequent braking. It uses radar to determine the distance to the vehicle in front and its relative speed, and gives a visual and audio signal when braking is required. It automatically applies the brakes when the driver releases the accelerator. Some manufacturers are developing sensor fusion of radar and vision data to give rapid and accurate range and speed information along with object identification. The radar picks out the close obstacles that pose a threat, and the vision processing homes in on the appropriate part of the image to give rapid identification.

Car manufacturers are developing infrared vision systems to assist drivers at night. Near infrared systems use headlights that emit wavelengths in the range 750-3,000 nm, and pick up the reflected radiation, forming an image that is easy to interpret. Far infrared systems detect the radiation at 5-30 μm naturally emitted by objects at ambient temperatures, and the resulting images are more difficult for the driver to interpret. Honda uses image processing with knowledge-based classification to detect pedestrians quickly and automatically in these images. It is important to display the resulting information in a way that informs without distracting or overburdening the driver, and Professor Joseph Krems at the Chemnitz University of Technology is one of the researchers exploring the best way to do this by evaluating prototype systems (Figure 4).

FLIR Systems Ltd has brought out the PathFindIR infrared camera (Figure 5) enabling drivers to see up to five times further at night than with ordinary headlights. The camera is hermetically sealed to withstand the weather, and has a high-impact resistant window, and integrates into the front of the vehicle. It transmits NTSC video images via a 12-pin automotive connector to a display inside the car. It covers the 7.5-13.5 μm range with a 320×240 pixel microbolometer sensor and has a 36° field of view. It is used in construction and emergency vehicles, and in high-end BMW cars.

Figure 4 Prototype infrared vision systems: the event-based warning system on the left signals the position of a critical object at night using LEDs along the bottom of the windscreen. On the right is a mirror-based system. These pictures were kindly supplied by Professor Dr J.F. Krems, TU Chemnitz, Allgemeine Psychologie und Arbeitspsychologie

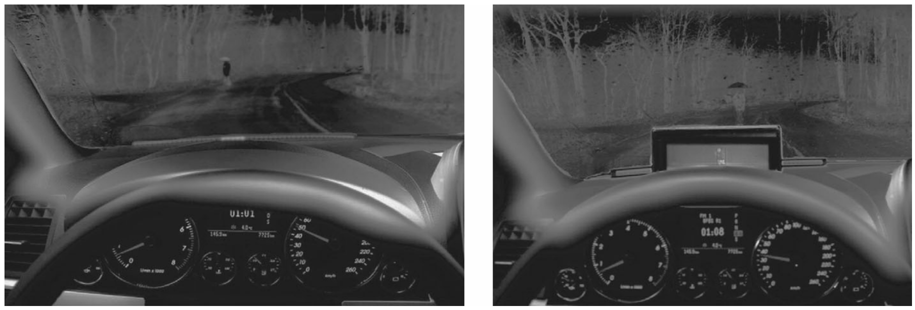


Figure 5 The PathFindIR infrared camera from FLIR is weather-proof and integrates into the front of a car or emergency vehicle to help the driver's night-vision

Unmanned air vehicles

In July 2005, the UK Government decided to fund the ASTRAEA programme (autonomous systems technology related airborne evaluation and assessment) involving industrial and academic partners to develop safe autonomous flight without the need for restrictive or non-routine conditions, claiming that this will bring economic, environmental and security benefits to the UK. Anticipated applications include agricultural and geographic surveys, pipeline inspections, and surveillance by police, fire and coastal services. Unmanned air vehicles (UAVs) are already used by the military as spy planes or drones, but currently in the UK they are kept in segregated airspace. Small civilian UAVs are allowed in unsegregated airspace under specific restrictions and regulations Directorate of Airspace Policy (2005), and the intention is to improve sense-and-avoid technologies so that UAVs can respond and manoeuvre to the same extent as piloted aircraft.

Aircraft are a long way ahead of cars, equipped with a range of pilot assistance and autonomous systems such as automatic take off and landing, automatic navigation and autopilot facilities. For example, the SkyWatch HP (Figure 6) is an active surveillance traffic advisory system. It interrogates the transponders of aircraft in the vicinity, calculates their distance, bearing, relative altitude and speed of closure and alerts the pilot by audible signal and visual display of any collision courses. The system can track up to 35 aircraft at once at distances of up to 35 nautical miles, giving the pilot

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Figure 6 Skywatch HP from L-3 Communications Corporation interrogates the transponders of nearby aircraft alerts pilots to any collision courses

30 s warning of collision assuming a closing speed of 1,200 knots. The system was originally made by Goodrich, but is now owned by L-3 Avionics. L-3 makes another collision-avoidance system called LandMark (Figure 7), which warns if the aircraft is on course for a collision with the surrounding terrain.

Between 1999 and 2003, NASA experimented with a UAV called Proteus at the Dryden Flight Research Centre as part of its Environmental Research Aircraft and Sensor Technology program. The autopilot and satellite communications systems on the aircraft allowed ground-based staff to control it "over the horizon". In 2002, the plane was equipped with Skywatch HP to detect other aircraft with transponders so that the ground pilot could change the aircraft's direction or altitude to avoid collision, and in 2003 a small 35 Ghz radar system and an infrared optical sensor were added to detect aircraft without transponders. The optical system detects a potential colliding object and the radar measures its range and closing speed.

By adding algorithms to calculate routes through the surrounding traffic and terrain, and actuating the aircraft controls to follow those routes, UAVs would be able to carry

Figure 7 L-3's LandMark system warns if the aircraft is on course for a collision with the surrounding terrain. The 8100 model has integrated GPS and 320-mile range

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out autonomous collision avoidance. Key areas identified in the ASTRAEA programme include adaptive routing, collision avoidance and multiple air vehicle integration, and researchers at various UK universities are investigating techniques and evolving new algorithms to address these needs.

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