Intelligent Sensor Based Road Vehicle Driver Assistance

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Abstract

This paper concerns research towards the provision of a rich set of road vehicle driver assistance modes to reduce the stress and improve the safety of negotiating both on-road and off-road terrain. These modes include navigation planning, potential collision warnings, blind spot and rear traffic monitoring, backing assistance, drowsiness detection and night vision enhancement. The approach taken is partially related to adapting instrumentation from autonomous and teleoperated robot navigation research; other aspects relate to human factors considerations. Progress to date is reported in detail.

1. Introduction

Recent robotics conference and journal publications in the domain of automated guided road vehicles [Thorpe,1997; Kimoto and Thorpe, 1997; Dickmans, 1993] would indicate that the current state of available technology is at a sufficient level to support, in principle, fully autonomous navigation, but perhaps not yet with sufficient reliability (in unpredictable circumstances) to overcome safety related legal barriers to widespread acceptance, at least in the realm of the public road systems. A practical alternative, at least into the foreseeable future, is to retain the human driver as the primary intelligent, controlling agent but to provide as much assistance as is reasonably possible in the form of route planning facilities, warning systems for potential collision or excessive speed, detection of the driver's diminishing ability to drive safely (perhaps related fatigue, drowsiness and/or alcohol or drug consumption) and perhaps other supporting capabilities such as automatic windscreen wiper and head light operations.

There are two basic classes of sub-tasks which make up the intended research - those which are concerned with critical and immediate safety issues and those which have the potential to reduce stress in a way which may indirectly improve safety, but would certainly make driving more convenient and enjoyable and perhaps more economical.

The first class requires real-time and reliably correct responses to situations of imminent danger in a form which permits driver correction without panic and yet does not allow the driver to develop a false sense of security which may lead to negligence. This class includes warning of potential or imminent collision from any direction but particularly in relation to safe distance to a vehicle or obstacle in front, indication of the approach of an overtaking vehicle from behind or the side (particularly in the door column 'blind spot' area) and alerting the driver to inappropriate steering and/or acceleration/breaking behaviour that may be associated with sickness, drugged state, inebriation or tiredness.

The second main class includes provision of tracking and mapping data along with optimal route planning and spoken directions. These provisions would not normally be regarded as urgent or critical but could still be of particular importance if they softened an otherwise potentially stressful situation.

Drowsiness detection, whether it be by monitoring the frequency and duration of eye closure, head nodding or body slumping bridges the two classes, since early detection could defuse a potentially critical situation but is not as urgent as actual imminent collision warnings.

Perhaps the simplest way of providing details of the research is to first deal with conceptual sensor and methodological issues and then with system implementations, operational issues and outcomes to date.

2. Concepts, Sensors and Methodologies

Global Positioning Systems (GPS) capable of specifying the position, orientation and velocity of a vehicle very accurately are commercially available but are currently very expensive. However, relatively inexpensive systems can provide 50 metres r.m.s. (root mean squared) position accuracy fixes which may be sufficient for road navigation advice. Until recently, an intermediately expensive way of achieving 10 metres r.m.s. accuracy was to utilise a differential mode GPS system involving fixed stations transmitting correction data to mobile units to compensate for deliberately introduced clock errors (selective availability). However, the recent 'turning off' of the clock error has permitted near differential GPS accuracy capabilities to be achieved with stand alone mobile units. The most accurate results require phase mode analysis of the carrier wave signals and is still quite an expensive alternative.

Three or more satellites of the GPS set of 24 (21 in operation, 3 spares) must be in line-of-sight of the receiver for a valid position fix. In built up areas, the likelihood of not meeting this requirement for short periods is quite

high. For continuity of tracking, backup is required; this can most easily be provided by odometry (measurements of wheel rotation) which can return fairly accurate relative position and bearing information for short periods but is subject to accumulative errors over time due to wheel contact variation, slippage and distortion as well as ground undulations. Combining differential GPS (DGPS) and odometry is an excellent solution to this problem. Inertial Navigation Systems(INS) provide an alternative, but more expensive, back-up methodology.

Whilst GPS can return bearing and velocity as well as position it can only do so with acceptable accuracy when the vehicle is moving smoothly. To determine the direction in which a robotic vehicle is pointing when it is stationary, a flux gate compass can be used. On land such an instrument can be seriously perturbed through distortions of magnetic flux caused by ferric materials in surrounding structures, including those underground. On the other hand, an optical gyroscope of modest expense can measure rotational velocity and hence turning extent (through integration) but is subject to drift over time; combining flux-gate-compass and optical gyroscope bearing determinations offers a solution to reliable bearing determination which is functionally similar to the GPS/odometry combination for position determination.

Of course, differential odometry is also a source of relative change of direction and thus provides another means of bearing determination, but one which, like the use of an optical gyroscope, suffers from accumulative errors over time. However, in driver assistance terms, bearing determination is not a critical issue whilst position determination is as far as map route guidance is concerned.

Since many commercial GPS based car navigation systems with detailed directions for the driver already exist, there seems little point in replicating such systems as part of this project. Thus, while such systems will be integrated with other driver assistance components, the main emphasis will be on the other aspects such as imminent collision detection, hazardous driving indication and drowsiness detection. Both open country off-road and on-road GPS systems will be incorporated, however, since these modes differ in some respects.

For potential collision detection, both passive and active rangefinding are of value. For this project, a scanning active (time-of-flight) range finder capable of providing a set of range values at 1/2 degree intervals over a 180 degree sweep in one second with an accuracy of several centimetres up to a maximum range of 50 metres is used. Another source of range data will be provided by passive stereopsis. Whilst it is possible to consider 360^0 ranging, the forward component is most critical; thus active and passive rangefinder systems are best deployed with a forward aspect.

Erratic driving behaviour can be easily detected by instrumenting the acceleration, braking and steering mechanical systems with the appropriate linear and rotational movement encoders, and setting up, through experimentation, tolerance limits for combinations of such movements outside of which unacceptably erratic (hence dangerous) behaviour is clearly evidenced. The attraction of this approach is that unacceptable and dangerous behaviour can be detected objectively, whatever the cause be illness, inebriation, drug ingestation, drowsiness or mechanical malfunction.

Relating measurable sensor quantities to danger of collision is a crucial aspect of the work and involves considerable conceptual and experimental development. It would seem best to avoid, if possible, subjective aspects such as mental state of the driver under various conditions, and concentrate more on the physics of the situation with regards to vehicle and driver behaviour in a variety of road and off-road environments and the measurable control actions taken by the driver.

Drowsiness detection is perhaps the most valuable driver assistance component, especially for long solo journeys, since it is a preventative approach to correct an unacceptable driving behaviour which is known to be the cause of many fatalities and other serious accidents.

Whilst alcohol and/or drug consumption in relation to driving are recognised criminal activities, drowsiness when driving does not incur the same societal outrage and thus many respectable people indulge, knowingly or otherwise, in this dangerous activity. It is also the case that the onset of drowsiness may not be consciously noted and appropriate action taken or that over-confidence lulls an individual into a false sense of safety. In any case, a reliable and unobtrusive/non-invasive means of early detection of drowsiness would be of considerable assistance to the average driver.

Placing targets on the forehead or eyelids of a driver or the requirement that the driver wear special glasses or a harness would allow a simple but probably unacceptable drowsiness detection scheme to be devised. The challenge is to come up with more passive means of detection. It is intended that a number of alternative schemes, including visual monitoring of the driver's eyes and face and other parts of the body as well as fitted mechanical systems would be researched. The early detection of eye closure and eyelid droop patterns, including frequency and duration of relevant movements by analysis of video data streams is one of the more interesting approaches worth investigating in detail. Ultrasonic detection of head movement from behind may well be another.

An alternative approach, which in some sense is invasive but does not rely on the driver volunteering to don special equipment, is to require that certain alertness tests be carried out at regular intervals. Failure of these tests could trigger graceful slowing down of and eventually disabling of the vehicle. Such a system could become a standard manufacturer's built-in feature of a modern vehicle.

When it comes to alerting a driver of impending danger or giving advice on appropriate routes etc. the quality and style of the reportage is very important. What is to be favoured is a informative mode, with gradations of urgency apparent, which does not unduly distract the driver from safely carrying out the appropriate response to the report. A pleasant voice giving succinct information with the appropriate inflexions and volume plus associated, perhaps partially redundant, visual displays, could provide a uniform way of alerting the driver to imminent danger as well as giving advice on favoured responses. This research project will include studies of this important aspect of driver assistance.

Overall, this research project is intended to result in the construction of an integrated scheme of driver assistance along the lines indicated above, embodied in a working demonstration vehicle.

3. Implementation to Date

Some of the ideas outlined above have now been tested in a demonstration vehicle [Figure 1]. The vehicle is a Mitsubishi four wheel drive van; thus both on-road and off-road experiments can be undertaken with it. A generalised inside view of the vehicle is shown in Figure 2.

Figure 1. Demonstration Vehicle

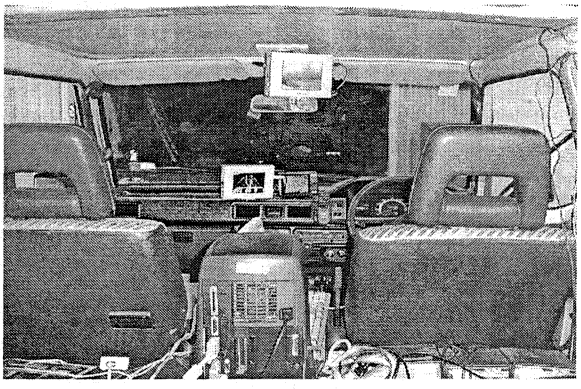

Figure 2. Inside View

Panoramic Viewing

The dome visible on the rear roof [See figure 3] of the vehicle houses a colour camera on pan/tilt mount (Directed Perception Inc.) which is controlled by a joystick within easy reach of the left hand of the driver. A $\pm 180^0$ pan and a $\pm 60^0$ tilt are available. The pan/tilt unit can also be driven under computer control, which option may prove useful in the longer run. This camera can be used to monitor traffic conditions around the vehicle and, in particular, can watch either for overtaking traffic which might ordinarily be obscured behind 'the blind spot' or rear traffic. At night the camera is excellent for low light vision. A colour LCD monitor for this camera is provided near the rear vision mirror [See Figure 4]. The driver is thus easily able to compare the limited rear view mirror view of the traffic with the much more complete view available from the camera.

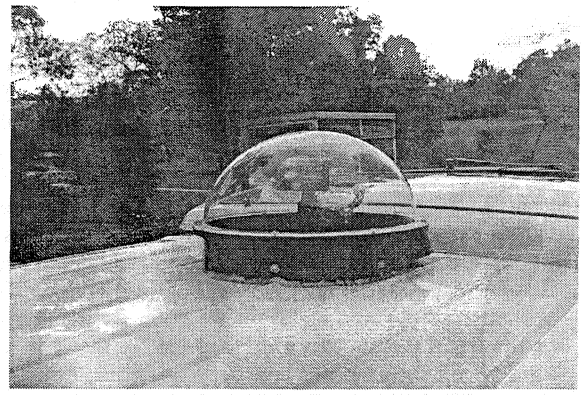

Figure 3. Pan/Tilt Camera Dome

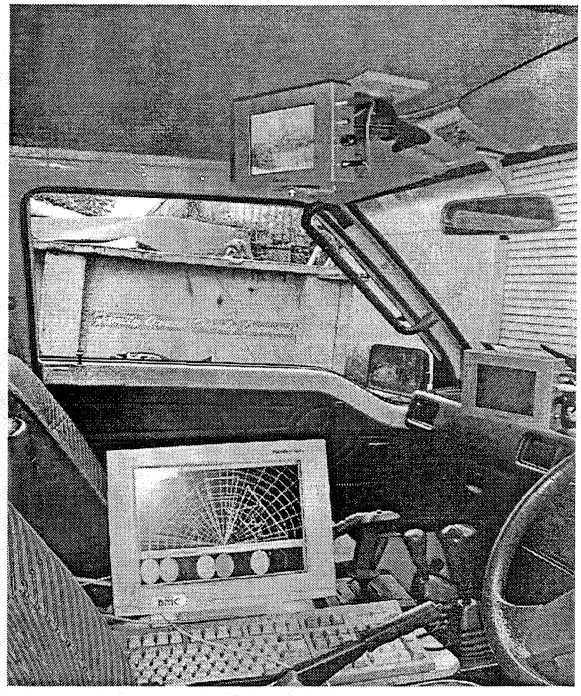

Figure 4. Pan/Tilt Camera View Near Rear Vision Mirror

Ultrasonic Rear Proximity Warning

On the rear of the vehicle, just above the bumper, two ultrasonic range sensors (Bosch) provide close proximity warnings which can assist when backing and indicating when a following vehicle is too close. Both audio and visual warnings are provided.

Night Vision Camera

Inside the vehicle a camera with its own infra red light source for night vision (Sony) allows night vision enhancement for the driver. This might be particularly useful when driving on country roads where crossing animals might prove a hazard. The same monitor used for the roof-mounted camera can be used for night vision camera viewing when selected.

Laser Rangefinder for Potential and Imminent Warnings

Under the front of the vehicle, just forward from the wheels, a scanning infra red rangefinder (Erwin Sick) is mounted facing forward [Figure 5(a)]. It can return 360 readings up to 50 metres at $1/2^0$ intervals over 180^0, as mentioned earlier. A down blast of air is provided in front of a slit in its protective (from rocks etc.) enclosure to deflect water droplets when driving on wet roads. This facility has not yet been fully trialled as to effectiveness.

The rangefinder data is acquired by a Silicon Graphics workstation (0_2) on a serial line at 9600 baud and displayed on the workstation monitor [Figure 5(b)]. The viewing window on the monitor can be adjusted to correspond to the frame of a video output facility provided, enabling the rangefinder data to be viewed on a TV monitor mounted on the front ledge of the vehicle in a convenient location for the driver to view it without taking his/her eyes off the road [See Figure 6]. Nine polygon sectors can be interactively specified on the range data screen using the mouse; these can be saved for recalling when needed. Intrusion into each sector is indicated on a disk of colour on the screen. There are three red, three orange and three yellow disks. The yellow disks would ordinarily be used for weak warnings for left, centre and right areas; the orange for medium level warnings and the red for critical warnings. The sizes of the disks can be adjusted at will. The inclusion of audio warning signals associated with the nine disks has been considered but not yet implemented.

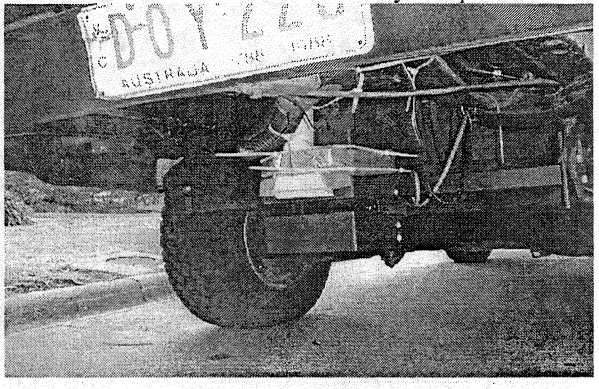

Figure 5.(a). Erwin Sick Rangefinder

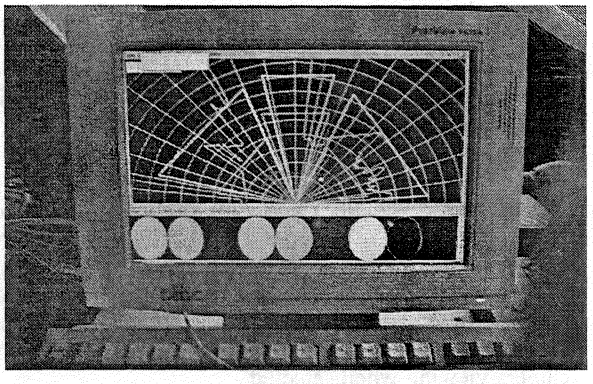

Figure 5(b). Monitor View of Range Data Protection Zones and Warning Disks

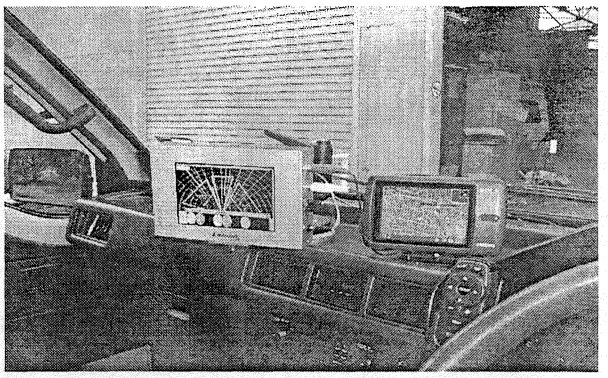

Figure 6. Range and CARIN Navigation System Monitors

Passive Rangefinder 3D Monitoring

Commercial systems providing rear frame rate disparity (inversre range) maps by applying stereopsis matching principles to the image data from two or more cameras are now readily available at modest cost. Since the laser rangefinder described in the previous section scans only in one place (in this case horizontally forward) obstacles not in that plane (eg. overhanging tree branches and constructions) remain undetected and thus not warned against. Using a stereopsis based area rather than planar scan could perhaps assist in these circumstances. The Triclops three camera stereopsis system (Point Grey Research) includes a demonstration program in which image details of all objects detected closer than some specified distance can be shown with the remainder of the scene blacked out. It is intended that experiments be carried out with a Triclops system facing forward from inside the vehicle to see whether this capability is of any practical use for obstacle detection. Unfortunately, the camera base line distances are so small that accurate ranging beyond several metres may not be possible and thus obstacles not detected by the laser rangefinder might be detected only too late by the passive rangefinder. If these experiments show promise, however, automatic alarms based on passive stereopsis can be easily built.

Map Based Navigation System

A comprehensive road navigation system (Phillips Carin 520) has been provided to guide the driver along favourable routes to nominated road junction destinations. The system is map based using CD data covering relatively large areas of metropolitan and suburban regions, separate CDs for each capital city covered (in the Australian system). Map data can be viewed at a variety of scales from tens of kilometres to hundreds of metres across the video screen provided.

In addition to a map based route-planning capability, the system uses GPS, odometry and gyroscope data as a sensor fusion mix to provide a highly reliable vehicle tracking facility. The GPS provides a rough fix of position; this is refined using odometry and gyroscope data (both prone to accumulated error) which provides the means of discovering a match in the map data in the vicinity of the GPS fix. Once tracking commences the map, odometry and gyroscope data can maintain vehicle tracking even when GPS outages occur for limited periods,

as in tunnels and in built-up areas. The system has proven remarkably reliable and easy to use. At traffic hold-ups alternative routes can be requested. An even, soothing voice provides advice on routing details including when turns are to be anticipated, which lane to take and which round-about exit to use. If an overshoot error is made by the driver the voice will suggest a U-turn when possible and will eventually suggest alternative ways to get back on track.

Ignoring advice simply leads to voice directions being adapted to the current position of the vehicle and the most appropriate road plan to reach the specified location from that position. Thus, if a home destination is provided, one can explore unknown areas as far away as one likes, just ignoring the instructions (or turning the voice off) until ready to go home, all the time viewing the tracking and map data. Not being able to get lost takes a lot of stress out of driving in an unfamiliar place.

For off-road excursions a hard copy map GPS system (Azimuth/Pointer 2) can be used. This provides location data as a plotter position over the map but does not give path planning advice. This type of planning could be provided using methodologies devised earlier by the author [Jarvis, 1995] but the need for this is questionable.

As mentioned earlier, the removal of the deliberate clock error (which was previously introduced for security reasons) now permits quite accurate GPS data (10 metres r.m.s.) from a stand alone unit. This is particularly valuable for outback off-road navigation since stationary GPS stations for differential mode support are generally located on coastlines to provide maritime navigation service.

Drowsiness Detection

It was always accepted that drowsiness detection, whilst of utmost value to drivers, since many fatal accidents (particularly on country roads or otherwise deserted roads) can be attributed to fatigue and drowsiness (whether long activity, stress or substance abuse related), would be difficult to instrument if intrusive methods (such as wearing special harnesses or glasses etc.) were to be avoided. Methods that came to mind included measurement of skin resistance, hand pressure on the steering wheel, steering wheel rotation patterns, brain wave monitoring, blink rate and dwell measurements, and posture change detection.

Some strong progress has been made in gaze direction detection [Heinzmann and Zelinsky, 1998] and the author is certainly keen to experiment with such systems in due course. Some of the other approaches are also worthy of careful assessment.

The notion of relating driver head posture to fatigue and drowsiness started to take shape as a relatively untried idea worth following up, particularly if novel yet reliable and relatively unobtrusive instrumentation could provide the necessary data. At first it seemed as if monitoring the forward/backward movement of the drivers head using an ultrasonic distance measuring device would be a good approach. On second thoughts such a system might prove too simplistic, as only one measure would be the basis of judging whether drowsiness was setting in. After all, discovering a sleeping driver is not as useful as a warning about that possibility in the near future.

In a fit of minor inspiration the author thought of using a Polehmus 6 degree of freedom tracker [See figure 7] which uses electromagnetic fields to determine the location and pose of a small receiver (approximately 1 cubic cm in size) relative to the transmitter (approximately 4x3x3 cm). This device is well known in the Virtual Reality community for hand and head tracking.

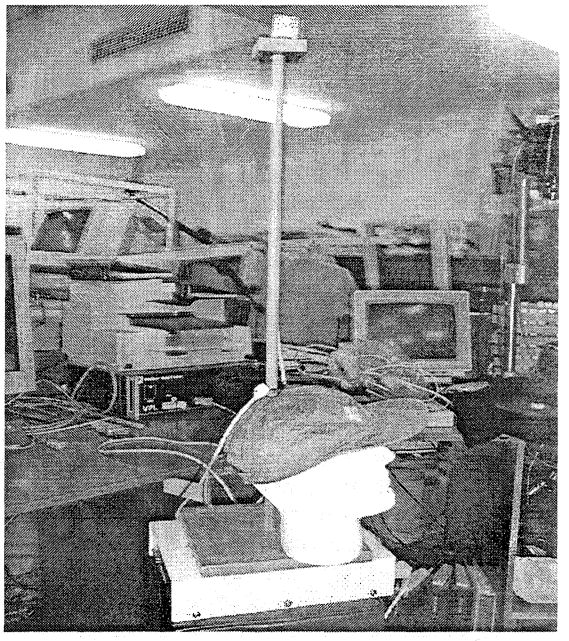

Figure 7. Polhemus 6 Degree of Freedom Tracker

Attaching the receiver to a cloth cap worn by the subject allowed some preliminary experiments to be carried out to determine whether drowsiness detection via head pose variations could indeed be reliably detected using this instrument. If the experiments were promising (as they turned out to be) it was felt the receiver could be suspended behind the driver so that head contact against a slight elastic resistance would 'attach' the device to the driver's head without much intrusion and little inconvenience.

The following experiment was carried out:

1. For a medium length period (say 50 seconds), collect all six degrees of head pose data over a range of small movements which are consistent with alert driving.
2. Analyse the data arrays and calculate the mean and standard deviation of each of the six degrees of freedom parameters (X, Y, Z, Yaw, Pitch, Roll).
3. Over a shorter period (say 10 seconds) collect the same data. Again calculate the mean values.
4. Issue a 'doze warning' for any occurrence of a mean value from 3, above, differing by more than 3 (arbitrary) standard deviations from the means calculated in 2, above.
5. Return to 3 and continuously repeat stages 3 and 4.

It was found that slouching, peering forward, drooping the head, deliberate stretching of the neck or moving unnaturally sideways all caused warnings that seemed to be appropriate for the experiments carried out so far. The

elegant thing about this approach is that the 'calibration' phase of 2, above, will provide individual data for each driver and for each driving session. Assuming that the driver is alert for 50 seconds at the beginning of a drive seems reasonable. More complex analysis can of course be included, such as tracking patterns of movement characteristics of alert and drowsy driving and making comparisons between them. This has not yet been done, but the first simple experiments have been very promising and the author is convinced this is a good way to go on the question of drowsiness detection.

4. Discussion

The pan/tilt controlled camera, the road navigation system, the laser rangefinder front collision warning and the ultrasonic sensor rear collision warning systems have been trialled extensively over the last year or so and have proven to be both reliable and useful. The night vision enhancement system has only just been implemented but its usefulness is in some doubt. The drowsiness detection system based on head pose variations is likely to be very effective but is difficult to trial in realistic situations without endangering the driver. Some laboratory based experimental test will need to be devised to properly measure the reliability of the system to actually test drowsiness without a high occurrence of false alarms rather than detect movements a subject might simply think can be associated with drowsiness.

Instrumenting the steering wheel to detect erratic use may be of value in detecting dangerous driving behaviour that might not be sleepiness related. Vehicle velocity and acceleration monitoring could also assist. However, these kinds of measurement have not yet been tried. Checking if head pose is consistent with steering direction may be another way of detecting unacceptable driving behaviour, particularly that associated with steering drift.

Devising appropriate warning modes with a mixture of audio, visual and tactile cues without introducing either confusion or distraction side effects will be a challenge in its own right. Another fascinating aspect of this work is the realisation that increased human laxity in reaction to safety device availability may neutralise the potential gains. Coming to grips with this issue in a reliable way will take some creative effort and good design and implementation.

5. Conclusions

This paper has described a number of modes of assistance to a vehicle driver, which would either directly improve driver safety or at least reduce stress and fatigue, which in turn might indirectly increase safety. The most critical direct safety features relate to imminent front collision warnings and drowsiness detection. However, mapping and navigation support plus panoramic viewing, night vision enhancement and rear collision warnings are all contributors to safe driving and stress reduced means of getting from one place to another or simply exploring unknown territory. The research so far has been promising but more work has yet to be done to reconcile technological advances with human factor considerations. Cost, to date, has not been a serious consideration since concept testing has been emphasised rather than market potential.

Borrowing ideas and instrumentation from the research domain of intelligent robotics and especially autonomous and teleoperated robot navigation has been a way off achieving a running start in this research.

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