VEHICLE SAFETY SYSTEMS

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Abstract

This invited short paper reviews some new remote control and computer-linked systems that may increase safety. A new development is the replacement of mechanical links between the driver and the road wheels with electrical wires. This may apply to one or more of the primary systems such as brakes, steering and throttle. The remote control network, generically termed X-by-Wire will be routed through an on-board computer, allowing control systems to manipulate driver inputs. This has implications for safety. A combination of X-by-Wire systems may facilitate quicker reaction times, especially for evasive action and stabilising cars. When driver monitoring systems and lane keeping technology matures, computers may be able to assess the roadworthiness of the driver and act accordingly. While theoretically sound, reliability coupled with a loss of driver involvement is a concern.

Keywords: safety, steer, wire, brake, drive.

Introduction

This invited short paper reports on X-by-Wire technology. Technology has tended to increase safety and future car systems should continue this trend. They may be faster to react and evasive action will be better executed since a driver may be quicker to respond and systems may maintain stability during manoeuvres. Through computer control, cars may become less likely to crash as onboard systems recognise when drivers are not fit to drive. It has been estimated that 30-40% of accidents happen because of drowsiness or lapses of concentration. Finally the removal of solid mechanical links will reduce chest injuries.

The number of people injured on UK roads in 1996 was 320,302 and of those 3,621 were killed (compared to 6,366 in 1975 [Statistics(1997)]. Road user casualties have continued to fall since this data was collected. Total casualties in 2003 were 290,607, 4 percent fewer than in 2002 and 508 people were killed on Britain's roads in 2003 (about the same as in 2002). The number of people seriously injured fell to 33,707 in 2003, 6 per cent lower than in 2002. Pedestrian casualties fell by 6 per cent between 2002 and 2003 and the number of pedestrians killed or seriously injured was down 8 percent. Conversely the number of road users is increasing so that the overall casualty rate per hundred million vehicle kilometres fell by 9 percent last year because of increases in traffic.

Current technology and advanced design is largely responsible for the improvement. Contemporary systems range from seatbelts to better brakes, now supported with ABS (anti-lock braking system) and airbag technologies. Modifications to the car body have seen crumple zones to absorb impact energy from frontal collisions, and side impact bars that protect from the second most common impact. Recent to the market are dynamic stability control systems – such as ESP (electronic stability program) that aim to stabilise the car when human reactions are not fast enough.

Fitting an airbag to a motorcar increases the occupants' chance of survival by up to 11%. Furthermore 85% of prospective car buyers sight ABS, airbags and traction control as key elements of their purchasing decision. Today, more than ever before, safety sells cars [Sanders (2003) and Sanders & Baldwin (2001)].

Conventionally, steering, acceleration and braking have been inextricably linked with the driver's commands, regardless of whether they're right or wrong. For example, the steering wheel is connected to a shaft, which in turn drives a steering rack thus turning the wheels. With new technology, electronic actuators could play an ever-increasing role. This is illustrated by Delphi Automotives power assisted steering in the new Fiat Punto. E-STEER$^{(TM)}$ eliminates the traditional system's ancillary equipment such as the power steering pump, reducing the energy drawn from the engine and improving fuel economy. E-STEER provides power steering even with the engine off.

Currently, cars have bundles of individual wires (often 250 or more), forming wiring looms [Sanders(2005)].

The intention is replacement by one wire running round the car; forming an automotive 'bus' analogous to that of a computer. The benefits from a reliable system include shedding more than half the wiring within the car, saving up to 15kg. Changing between left and right hand drive could be cheaper as the network could posses 'plug and play' abilities. Again, like a computer, the 'standard' computer on the car can then by programmed as to what type of car it is, allowing future upgrades, for example updating of brake control software.

Modern luxury cars include many extras such as automated seat positions and mirrors. The primary functions of the car remain traditional; nevertheless they all have potential to be replaced by electromechanical systems. X-by-wire may see the following 'X' systems integrated together:

Steer-by-Wire. A rotary encoder that detects wheel movement could replace the connecting shaft between rack and steering wheel. These signals could be passed to steering actuators. A further actuator could be added to the shaft of the steering wheel.

Brake-by-Wire. Future braking systems may be electro-mechanical. An electrical calliper is shown in Sanders (2005). This could result in shorter stopping distances, as brakes may be more efficient, since excessive pedal force may not be required in emergency stops. A full Electro Mechanical Braking system (EMB) is shown in Sanders(2005).

Drive-by-wire. Vehicles such as Toyota's Tundra 4WD employs an electronically connected throttle control; signals generated at the pedal are fed directly into the engine management system, resulting in quicker response, improved fuel efficiency and reduced emissions. Transmission may also be controlled remotely in a similar manner.

Additional systems

Active Suspension. Suspension keeps wheels in contact with the road, stopping dangerous pitch and roll of the car body, giving better stability for driving. Cars have to be sprung for passenger safety and comfort; the dominant frequencies in a car appear at 3-4 Hz and 10-12 Hz; the former is 'tyre hop' and has to be eliminated. Current systems are a compromise between: road holding, comfort and handling.

The Citroën Activa roll limitation system [Citroën(2004)], is based on automatic adjusting of suspension stiffness. Keeping the car horizontal helps spread the load to all four wheels, increasing grip by up to 30%. Elimination of body role also helps the driver to control the vehicle. Volvo's S60 employs a chassis control system similar to the Citroën using a conventional suspension system [Volvo(2004)] with electronically adjustable dampers; the Four-C system (Continuously Controlled Chassis Concept) is designed for more responsive automotive handling and safety.

The S60 has DSTC (Dynamic Stability and Traction Control) similar to ESP, and electronically managed all-wheel drive. Both are linked to the car's onboard computer allowing the combination of the damper system and stability control, providing control over the handling and stability of the car.

42V Architecture. Modern electronics can amount to 40% of the cars value [Professional Engineering (2001) and Automotive Engineering (2000)]. Due to increased power demands from ancillary equipment approaching the practical maximum of today's cars, a dual standard is evolving. Higher power is demanded from new components such as electronic steering and braking systems. To get the equivalent power at 12 V means an impractical increase in current – and hence the thickness of cabling and cost. Running at 42 V addresses this. A transitional period where cars run dual voltages using DC-to-DC converters is likely.

Some of the costs of 42 V can be mitigated by starter-generator systems; Bosch's system has efficiency levels of 80% across the entire speed range, and outputs 8 kW at 36 V. Conventional 12 V alternators output 1.5 kW, with maximum efficiencies of 70%, reducing to 30% at high speeds [Marsh (2000)].

Guiding the car. Radar or Laser guided cruise control is already in place on luxury cars such as the Mercedes S-Class; if traffic in front slows then proportional distances can be maintained. Nissan is working on a stop/go system – which effectively drives in rush hour traffic [Professional Engineering(2001)]. Additionally their lane support system refers to the white lines marking out the lanes. Optical sensors are mounted on the rear view mirror to steer the car at speeds between 40 Mph and 62 Mph [Professional Engineering (2001). These systems show the ability for computers to aid in driving. A prototyped low-cost radar based anticipatory pre-crash sensor is capable of providing critical pre-collision data to passenger restraint systems, enabling earlier airbag deployment or activation of seatbelt pre-tensioners. Inventors claim extensive testing has proved the system to be immune to false alarms from roadside objects, nearby passing vehicles and pedestrians [Taskin and Ismail (2000)].

Monitoring drivers. Systems devised to alert drivers to their increasing drowsiness are under development by Delphi automotive systems. Since a major safety issue is diminished driver attention, these systems could provide a vital warning before disaster [European Automotive Design (2001) and Professional Engineering - March (2001)]. Additionally Delphi's occupant detection system can sense the weight of the occupant on the seat, aiding better airbag deployment [Automotive Engineering (2000)]. Combine a heart rate monitor and camera surveillance with the driver's weight and awareness, and onboard computers may assess the 'roadworthiness' of the driver.

Figure 1: Joystick

A smart car presented by Oliver *et al* (2000), uses a system that on average predicts one second in advance of a driver starting a manoeuvre. Reaction times may be reduced through this anticipative technology, as the car is 'prepared'.

Amalgamating the systems

The R 129 prototype by DaimlerChrysler illustrates the concept and is shown in figures 6 to 8. A side stick controls the car. An onboard computer controls X-by-wire systems, including automatic transmission. Pushing the stick forward causes acceleration; speed is maintained by modified cruise control until further input. Pulling back induces braking. Sideways movement of the stick controls steering. Lights and windscreen wipers can be automatic. Buttons on the side stick shown in figure 1 operate turn indicators and the horn.

Drivers of conventional vehicles require, on average, 0.2 seconds to move their foot from the accelerator to the brake pedal [R19 (2003)], translating into a greater braking distance. The side stick may have potential for quicker reaction times.

Figure 2: R129 concept car in action
[Reproduced from Automotive Engineering (2000)]

Figure 3: On-board electronics for the R 129
[Reproduced from R19 (2003)]

Steering ratios are automatically adjusted to the vehicle's speed; the steering is desensitised to avoid over control. Elbow supports reduce effects of centrifugal forces on the side stick that could lead to steering errors. However, a Ford spokesperson argues that the side stick still offers irritation from these forces, saying most motorists will favour a symmetrical steering wheel.

Intelligent knowledge-based system. An intelligent knowledge-based system (IKBS) for fault diagnosis and supply restoration in a vehicle has been described by Sanders (2005). The system is based on techniques used successfully in the electrical power supply industry. The IKBS communicates with a simulator-store that remembers past faults. Scenarios are described to illustrate fault diagnosis and supply restoration. Knowledge based systems (KBS) have demonstrated practicality in the area of power-system diagnosis and restoration [Sakaguchi & Matsumoto(1983); Hotta *et al* (1990); Ma *et al* (1992)]. A simple PC-based KBS was built during this work to demonstrate the potential for electrical power system diagnosis and restoration in a vehicle electrical network. The KBS communicates with another PC-based vehicle electrical-system simulator (VEHSIM). VEHSIM represents the real electrical power-system in a “fly-by-wire” vehicle that constantly supplies analog and digital information to the KBS. The VEHSIM-KBS system realistically mimics the corresponding state of a vehicle electrical network. During testing of the system, scenarios such as cable faults, component malfunctions and loss of battery or alternator sources were set in VEHSIM. The system attempted to diagnose and restore the system using the built-in generic diagnostic rules and restoration algorithmic tools in the KBS. Capabilities were provided for the KBS to build its knowledge base through machine learning, and to retrieve the knowledge later if the same network conditions occurred again.

The environment

DaimlerChrysler conducted tests with a driving simulator on 17-year-old student drivers. Reportedly, side stick users had virtually no problems when dealing with critical situations, compared to the control group using conventional controls; 8 of the 32 drivers with conventional controls would have caused an accident by late braking. Drive by wire systems may have an impact on safety; dangerous manoeuvres that would undermine the stability of a car could be blocked and quicker reactions could increase evasive action possibilities and effectiveness.

High redundancy may have to be employed, termed ‘Fault Tolerant Systems’ by the manufacturing fraternity. Moreover modern fighter jets are flown using fly-by-wire techniques, and passengers do not worry exceptionally about travelling in an Airbus. When most conventional vehicles are exposed to side winds, the vehicle veers off course and the driver must steer accordingly to counteract. With X-by-wire, these effects are removed - the sensors immediately register a deviation from the desired course and the wheels are automatically turned to offset the effect of the side wind.

A side stick or pseudo steering wheel offers additional passive safety benefits. If there is no steering column, then there is also no danger of the chest injuries often caused in an accident says Daimler Chrysler researcher Friedrich Böttiger… And if the driver's foot can no longer get caught in one of the pedals during a collision, then the number of foot injuries will also be reduced. With the potential demonstrated by lane keeping systems [Betke & Mullally (2000) and Taskin & Ismail (2000)], and the emerging ability for computers to recognise when drivers are losing control (particularly from lack of concentration) the car could drive and safely halt itself. This has implications on safety and accident reduction, since Christer Nilsson, head of safety at Saab estimates that as much as 30-40% of accidents are caused by drowsiness.

Chassis control systems may be questionable, as drivers cannot always tell where the limits of tyre grip are. These were highlighted recently by the driving of the Audi TT, where people overestimated the limits of the car [Baldwin AJ (2001)]. Drive-by-wire could have blocked moves that render the car unstable in the first place. Potential cost benefits are demonstrated with E-Steer by Delphi automotive; it is cheaper and more flexible than its mechanical counterpart. Systems are independent of left or right hand drive, since the steering wheel and controls may be placed whichever side is relevant, and simply connected to the central data bus loop - ‘plug and play’. Systems fitted to aircraft are ‘no expense spared’, which is prohibitive for the car industry. When competitive concerns are introduced then is economy going to play over safety? The same can be said for the safety critical components on today’s cars, however after decades of production, components tend to be at minimum cost – the same may happen to these new components. Moreover, car manufacturers justly say that the systems should be no worse than conventional systems.

Insurance companies are certain to cringe at the costs of repairing these new systems in cars, for example when passenger airbags are set off in a car the dashboard needs replacing – an expensive procedure. Further minor accidents will also necessitate the replacement of sensors and other ancillary equipment. The upshot is X-by-wire cars should, in theory, crash less. New X-by-wire systems promise to reduce fuel consumption, via the elimination of pumps, drive mechanisms, and critically weight. Current electronic operation of inlet and outlet valves provides a 15% improvement in consumption [Marsh (2000)]. The potential for elimination of hydraulic fluids is positive, for example, E-steer yields 2-5% savings [Marsh (2000)]. Fewer emissions will result from tighter combustion control, arising from more accurate information, especially from the throttle to the engine management system.

Future developments

NASA's neuro-engineering laboratory has developed a control system for landing aircraft that relies on nerve signals arising from a clenched fist [Professional Engineering – Feb (2001) as shown in figure 4. Neural net sensing software could control a motorcar in a similar manner to the DaimlerChrysler side stick. Additionally, Volvo's VPC [Marsh (2000)] may be integrated into this arm glove, further enhancing the driver-car interface for possible driver monitoring purposes.

Commercial systems may still be 10 years away. Concerns about safety will filter down from luxury saloons and purchasers of these expensive vehicles may become guinea pigs of the revolution. BMW hopes to introduce brake-by-wire on its 7 series and some systems will appear at a premium between now and then.

In due course, computers may take over some driving on congested motorways, employing technology similar to that of lane keeping, creating road trains and relieving the driver from the mundane motorway chore.

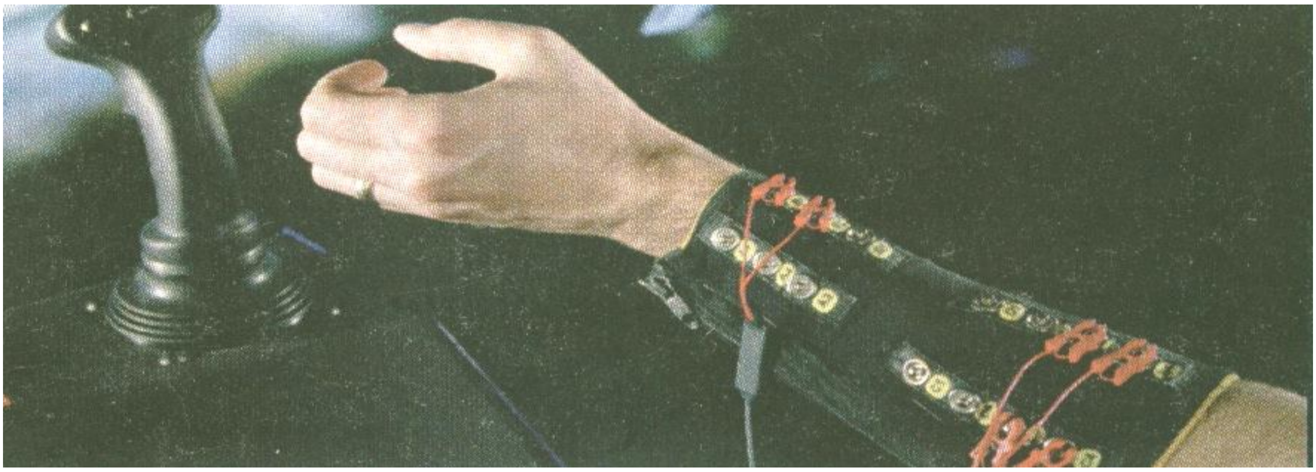

Figure 4: Arm Glove to sense nerve voltages
[Professional Engineering - Feb (2001), p55]

Another electronic concept is the accident notification system. In the event of a crash, a radio device begins to emit a distress call. This call brings help sooner than might otherwise be the case — especially in desolate locations with an unconscious driver. Volvos VPC supports this concept [Marsh (2000) and Volvo (2004)].

Conclusion

The proposed systems may lead to improved safety. Cars may be programmed not to crash and may have increasing margins of safety. Cars may perform better due to increased road holding. Unfortunately, the amount the driver actually *drives* the car is reduced (together with loss of *real* feedback). Loss of this involvement may be to the detriment of driver satisfaction.

Cost benefits and life saving potential of advanced systems are demonstrated by better reactions and stability; however, the most important criterion will be the reliability of the 'X' systems. Currently regulations require steering to be mechanically linked and drive-by-wire systems are not yet roadworthy [Automotive Engineering (2000)]. Further, motor manufacturers are still trying to agree on the protocol for the new systems.

The ultimate test for these systems will be the acceptance of the consumer; only once confidence can be placed in the systems will consumers be attracted. This is particularly relevant, as most people would not trust their computer to open a document without failing; will they trust computer-controlled cars?

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