

Vehicle Situational Awareness Technologies

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ABSTRACT

This paper presents the elements of an ongoing research program to develop, test and commercialize selected new technologies for smart cars to perform automatic signaling of a vehicle's intentions and to improve driver situational awareness at traffic intersections. The research builds on several previous projects and, as a guiding principle, is based on non-cooperative onboard technologies, allowing for a practical implementation that is designed to offer early benefits to equipped vehicles. The paper presents several of the technical trade offs in technologies for the systems and architectural considerations that were taken into account during the design phase.

INTRODUCTION

Vehicle traffic continues to grow at a rate that far outpaces the supply of new roads and highways. For example, in a study on California roadways, covering a 13 year period, the number of vehicle miles travelled increased by 45% while new road facilities increased by 5% to 26% depending on the road type [1]. Traffic demand increased at approximately twice the rate of new facilities over that period. Car ownership is also increasing as demonstrated in Figure 1. According to these U.S. Government statistics, the number of cars owned per U.S. household has increased by over 60% between 1969 and 2001 [2]. This is but one of many indicators of the ever-increasing growth of vehicle traffic in the United States, and elsewhere.

With the increase in demand for road facilities outstripping supply, the result is increased congestion and delay. According to a study conducted by Texas A&M University, traffic signal timing is a significant source of delay [3]. That research finds that much of this delay is the result of managing the flow of intersecting traffic, but some of the delay can be reduced if the traffic arrives at the intersection when signals are green instead of red. Furthermore, the study reports that each peak time traveller in an urban area is subjected to almost 40 hours of delay annually, while non peak travellers are subjected to

approximately 30 hours of delay annually. In this context, delay is defined as the extra time spent travelling due to congestion.

	Vehicles per Household	Licensed Drivers per Household
1969	1.16	1.65
1977	1.59	1.69
1983	1.68	1.72
1990	1.77	1.75
1995	1.78	1.78
2001	1.90	1.75

Figure 1: Growth in Vehicle Ownership

Travel delay calculations are classified as recurring (i.e., usual) delay or incident delay (due to crashes, vehicle breakdowns, etc.). Recurring delay estimates are developed using a process designed to identify peak period congestion due to traffic volume and capacity. Delay caused by other events is not included in recurring delay estimates, such as:

- Traffic incidents
- Work zones
- Weather
- Fluctuation in demand
- Special events
- Traffic control devices

The research described in this paper is part of a development program aimed at resulting in commercialised technologies to assist driver situational awareness, thereby improving traffic throughput and latency. The development and evaluation of two separate situational aids for drivers are presented, along with many of the technology and architectural trade offs being considered. The two applications under development and evaluation are automatic signalling of intentions and automatic detection of traffic light changes. Both applications have the same goal of improving driver situational awareness and driver response times.

The automatic signalling system is designed to allow a driver to choose between manual or automatic signalling of turns, deceleration, and acceleration and a prominent feature is that the system is not cooperative and can be phased in over time, one car at a time and offer immediate benefits. Much of the activity relating to newer automotive technologies relies on the use of cooperative technologies, such as transponders or beacons and the like, requiring all cars to equip in order to gain benefits. While this is technically achievable it is an institutional limitation, and therefore systems that do not rely on this extent of cooperation are more practical and can be introduced sooner.

The auto signalling system is designed to have the capability of ensuring that many more cars on the road provide proper turn signals as well as acceleration and deceleration signals. This display of intent will lead to increased situational awareness for all drivers and will improve efficiencies on the roads leading to less congestion. Today, the car ahead simply slows down leaving a following or approaching driver to wait and guess what is happening. The research and initial results show that this new technology has the capability to give the car ahead the capability to declare its intentions in advance, automatically.

The auto light detection system is designed to improve the flow of traffic on roadways, specifically at or upon approach to intersections that have traffic lights. With the proliferation of lighted intersections to control traffic and the seemingly increasing time that drivers have to wait for traffic light changes, this application automatically prompts a driver when a light change is detected, thereby improving driver response and reducing the cumulative wait time at intersections, thus benefiting all road users.

COOPERATIVE TECHNOLOGY TRADEOFFS

Aviation and automobile transportation face similar capacity problems. With limited concrete, or numbers of runways and airports, the number of flying passengers is estimated to double or triple over the next 20 years, while the number of new airports or runways that are being planned is merely incremental. The aviation industry views new technologies as key to accommodating demand with improved efficiencies and a slow growing infrastructure. For example, reducing the spacing between aircraft both vertically and horizontally, allows more aircraft to use the same block of airspace. Newer, more accurate, aircraft tracking technologies allow for this reduced spacing. On airport surfaces, accurate tracking combined with decision support tools allow more aircraft to use existing airport gates more effectively.

Automobile transportation may also benefit from new technologies that allow for more cars to use existing roads and facilities more efficiently. For example, these technologies may include smart traffic lights, vehicle

transponders and other on board systems. Cooperative technologies receive a lot of attention for potential future vehicle applications. Pioneered in commercial aviation, use of onboard cooperative devices, such as transponders, allows for communication of intent between users and third parties. In aviation, all aircraft are required by law to carry transponder devices in regulated airspace for applications such as surveillance and collision avoidance. With the order of 10,000 commercial and 250,000 general aviation aircraft in existence today, this is regulated by law, mainly because aviation is inherently global and governments have heretofore had responsibility for air traffic control.

For example, a vehicle transponder for pre-emption of traffic lights, developed by NASA, determines if a vehicle is approaching and has priority to pre-empt the intersection; it transmits a signal declaring the priority and the pre-emption to all participating vehicles in the vicinity [4]. If the unit at the intersection has determined that other participating vehicles are also approaching the intersection, then this unit also transmits, to the vehicle that has priority, a message that the other vehicles are approaching the same intersection. The texts of these messages, plus graphical symbols that show the directions and numbers of approaching vehicles are presented on the display panel of a computer that is part of the transponder in the vehicle.

While these systems have been designed and tested, and no doubt work effectively in technical terms, the problem with full scale implementation is institutional and not technical. The big issue with cooperative devices is that all or most vehicles need to be equipped to provide benefits overall. As in aviation, if one vehicle in a particular scenario is not equipped, the entire system is rendered useless and may be unsafe. Hence the non-cooperative approaches taken with the subject research in order to maximize benefits and operate in a mixed equipage scenario.

Figure 2 shows that, in the United States, the average age of a car on the road is increasing, from 7.7 to 9 years in the past 10 years or so [5]. While this is an average figure, it means that a great many cars being bought today will be on the road over 10 years from now. Regardless of the reasons for this increase in operational life, e.g., better reliability, it means that it will take longer to see the effects of any new legislation or mandates for new vehicle technologies. Certainly, we may see retrofit legislation, but normally that is the exception rather than the rule. So it is likely that newer technologies introduced sooner will be voluntary and after market. Again, this supports a strong argument for non-cooperative applications.

Cars	Lt Trucks	All Trucks
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1995	7.7	7.4	7.6
1996	7.9	7.5	7.7
1997	8.1	7.3	7.8
1998	8.3	7.1	7.6
1999	8.3	6.9	7.2
2000	8.3	6.7	6.9
2001	8.3	6.1	6.8
2002	8.4	6.6	6.8
2003	8.6	6.5	6.7
2004	8.9	6.4	6.6
2005	9.0	6.6	6.8

Note: Light (Lt) Trucks are $\leq 14,000$ lbs.

Figure 2: Median Age of U.S. Vehicles

AUTOMOBILE SIGNALING

This research builds on many other new automobile technology and sensor development projects. Use of radar sensors for various vehicle applications is well described in the industry. Radar sensors are becoming commonly used to assist parking, monitor blind spots, anticipate collisions, starting and stopping operation or during driving with distance monitoring, and to regulate separation through cruise control operation. New developments include the use of radar sensors using a single radar sensor mounted on each side of the vehicle to generate a range and range-rate value for detected target objects, and a controller coupled to each radar sensor [6]. The controller calculates estimated target object speed, angle of the target object line of travel, and a shortest distance value from the sensor to the target object line of travel, and compares the shortest distance value and a change in the angle value to respective threshold values for potential collision threat assessment.

Different Radar frequency bands and modulation techniques to monitor the near field region around a vehicle are also being used [7]. The motivation here is that current Radar sensors are normally used for remote object detection, and that, for near field observations, high spatial resolution is important for separation as well as angle, whereas the angular information is less important for large separations. For monitoring of separation at large range, Radar sensors are conventionally used having a frequency of approximately 76 Gigahertz. These frequencies have some disadvantages; however, and frequencies of approximately 24 Gigahertz are argued as being better for near field monitoring.

Taking the use of onboard systems and the smart car concept to a logical conclusion, there is, of course, growing talk of cars that drive themselves. A recent BBC interview with General Motors presented the likelihood of self-driving cars on the road as early as 2015 [8]. That interview also included a description of a competition held for 11 driverless cars that had to navigate around a 60 mile course without operator intervention. The cars had various sensor

devices onboard including radar and Lidar (light detection and ranging), GPS navigation, and databases.

AUTO SIGNALING ARCHITECTURES - Figure 3 is an overview showing the main elements of the auto signalling processes. This variation is a fully integrated system which interfaces with several other existing vehicle systems. The inputs to the system include sensor inputs including Radar, Lidar, and the vehicle's location, derived either from satellite navigation or inertial reference. Routing is estimated based on a combination of route history previously taken, time of day and date, and actual route guidance, from the vehicle navigation unit. For example, the potential route estimator would have a high degree of confidence in routes taken during the week at certain times pre-established times such as driving a child from home to school or a work commute. At different times or on weekends or national holidays the degree of confidence would be lower.

The turn decision estimator is a combination of the outputs from the potential route estimator, sensor inputs, and human inputs, which include control inputs such as gear changing, pedal movement, cruise control operation, and turn signal operation. Deceleration and acceleration are also inputs to the turn decision estimator. For example, if a vehicle is decelerating toward an intersection when there is no stopped or decelerating vehicle ahead, then it is more likely that the driver intends to make a turn.

In the architecture shown in Figure 3, the turn decision estimator powers an in-dash indicator to inform the driver that a turn signal will be given in a short period of time, for example with 2–3 seconds of initiating the in-dash indication. This gives the driver the opportunity to cancel the impending turn signal for any reason. A manual input is available for the driver to switch on or off the auto turn mode. For example, when using the system the driver may be planning a completely new route and may wish to disable the auto turn signal function. That new route would then be stored in the invention's route history for later use in turn decision estimation. The system will be designed to also to cancel manually initiated turn signals that have been inadvertently left on by the driver.

Through a combination of human inputs and vehicle dynamics, the system can determine whether the vehicle is accelerating or decelerating, and can power signals on the front and back of the vehicle. Vehicle dynamics are sourced from a combination of satellite navigation or other inertial or gyro sensors.

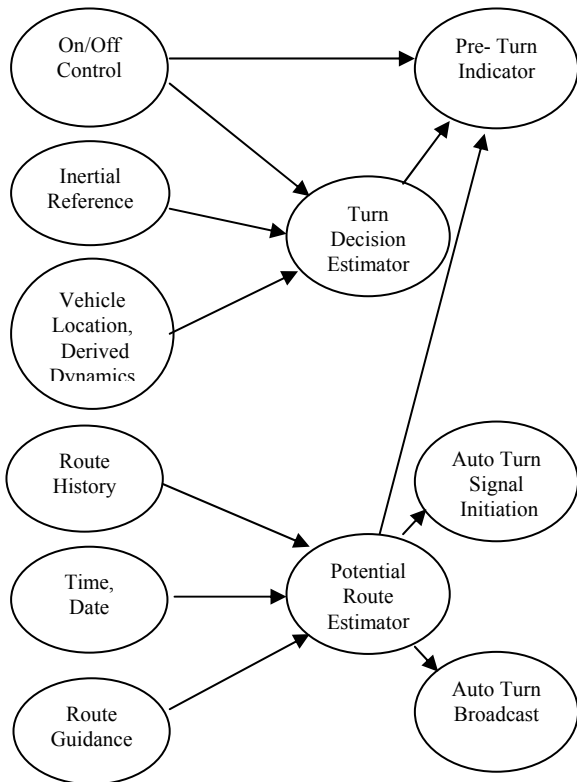


Figure 3: Auto Signalling Processes

In a variation of the system, a portable stand-alone unit is also being evaluated. This unit is intended to be completely stand alone or available as a function in a portable satellite navigation unit. The system has an on/off control and uses built-in sensors such as an inertial unit and radar sensor. For example, trade off analyses are being conducted to affix the Radar sensor to the rear of the unit so would scan the roadway ahead when the unit is placed on the dashboard of the vehicle. Vehicle location and route history may be determined by satellite navigation. As for the system shown in Figure 3, the combination of route history, time and date, and route guidance provide for estimates of the potential route to be taken by the driver. The potential routes combined with sensor readings and vehicle location provide estimates of upcoming turns. The inertial information and vehicle dynamics derived from satellite navigation provide deceleration and acceleration estimate to the turn decision estimator. The pre turn indicator, built into the portable unit will then indicate that a turn signal will be made within a selectable period of time, of 1–3 seconds, as currently estimated, before commencement of the turn signal. Since the unit is portable and not fully integrated with the vehicle it may send a turn signal initiation to the vehicle over a data link such as blue tooth, USB, or other hardwired interface. Once the turn decision has been made it will also be available for broadcasting over any standard data link to nearby vehicles (a future cooperative environment, which the author acknowledges).

INTERSECTION SITUATIONAL AWARENESS -

The automotive market is generally seeing development of many new systems to improve vehicle and driver situational awareness. One of these is a system that identifies a zone around a host vehicle and identifies a target vehicle in the zone [9]. The speed and location of the target vehicle are monitored and an alert is generated in the host vehicle if the target vehicle is moving outside of the zone at a speed higher than a minimum speed and the host vehicle is stationary. The system is used when a vehicle that is travelling in a series of consecutive vehicles stops due to traffic lights or a traffic jam, and the operator often fails to move the vehicle forward immediately after the traffic light changes or the traffic jam is cleared. This failure to move the vehicle forward may cause further delays or traffic jams to occur. The technique relies on forward-looking radar or other sensors to detect the motion of the vehicle in front.

In addition there is a warning and information system for a vehicle which outputs information that would normally be below a conscious threshold of perception for a human [10]. At least one signal source located in the peripheral field of vision of the user is provided, and its output signals are variable by adjusting their colour, intensity, frequency, timber, or loudness. The system is designed to warn the driver of hazardous situations which previously had to be recognized by the driver alone. For example, some complex ambient detection systems based on Radar, infrared, or image processing technologies have been implemented in Mercedes Benz S-class vehicles, where they support the longitudinal and transverse guidance of the vehicle through visual or acoustic information.

These types of information systems are usually designed so that a hazard warning is provided only when the driver has not personally perceived a hazard; otherwise the warning information has no utility. A European system has been developed and deployed which displays information in the form of images or symbols at least once for a brief period of time in the primary field of vision of the operator, the period of time being below a conscious threshold of perception by the user and above an unconscious threshold of perception. The purpose is to provide a warning and information system for a vehicle which will increase traffic reliability and support the driver of the vehicle with longitudinal and transverse guidance tasks.

Image Processing Trade Offs - Image processing systems are becoming more commonly used to aid in situational awareness for a variety of applications. A new development for vehicles is a two camera (forward and rear facing) system to detect and recognize the environment surrounding a vehicle [11]. The system is mainly aimed at recognizing various road markings. It offers advantages over conventional single camera systems that use only a rear facing camera to recognize objects surrounding the

vehicle, where images are road surface markings, but has difficulty predicting specific positions of road surface markings. Further, the angle of depression of single camera systems is large, and has a short period of time to acquire the object leading to low quality recognition and false marking recognition. Results of recognition including the object type, position, angle, and recognition time from an additional forward-looking camera are used to predict specific timing and position of field of view of the rear facing camera, at which the object appears. Recognition logic parameters of the rear facing camera and processing timing are then optimally adjusted. Further, luminance information of the image from the forward looking camera is used to predict possible changes to be made in luminance of the field of view of the rear facing camera. Gain and exposure time of the rear facing camera may then be adjusted accordingly.

One of the issues for traffic light pattern detection is the automated assessment of the presence of the colours red and green, which is to emulate the human sensation of colour due to the sensitivities of three types of neurochemical sensors (which are present in the cones of the retina) to different wavelengths in the visible region of the spectrum [12]. Each sensor is associated with one type of cone and responding to a range of wavelengths, with varying sensitivity. One type of sensor is maximally sensitive to short wavelengths with a peak response at approximately $0.44 \mu\text{m}$, which is the blue sensor and is insensitive to wavelengths longer than $0.52 \mu\text{m}$. The second sensor has peak sensitivity at $0.53 \mu\text{m}$, or green light. The third is the red sensor although peak sensitivity actually occurs at $0.57 \mu\text{m}$, the wavelength of yellow light. However; of the three, the third sensor has the highest absorption of red light.

Many camera systems emulate the functions associated with the human sensation of colour. Colour filter arrays are used to arrange colour filters on photo sensors, such as the Bayer filter mosaic, which refers to an arrangement of colour filters used in various digital cameras image sensors [13]. The Bayer filter is common on consumer digital cameras, and alternatives include the CYGM filter (cyan, yellow, green, magenta) and RGBE filter (red, green, blue, emerald), and the Foveon X3 sensor, which layers red, green, and blue sensors vertically rather than using a mosaic; or using three separate CCDs, or one for each colour. There are also various other types of sensors that filter based on colour.

Spatial Data - There are several systems available on the market including software and hardware for data analysis, pattern recognition and image processing, however; the task of identifying changes in status of traffic lights is relatively simple in terms of target association. As shown in Figure 4, the progression of a light change from red (stop) to green (go) is vertical, with the red light geometrically directly above the green light. The range of

the scale, i.e., the proximity of the red to the green is also quantifiable based on typical distances from the intersection to the position of the light. There are other identifiable patterns, such as the horizontal relationship between dual lights, as shown in Figure 4 where the dual reds and greens are shown.

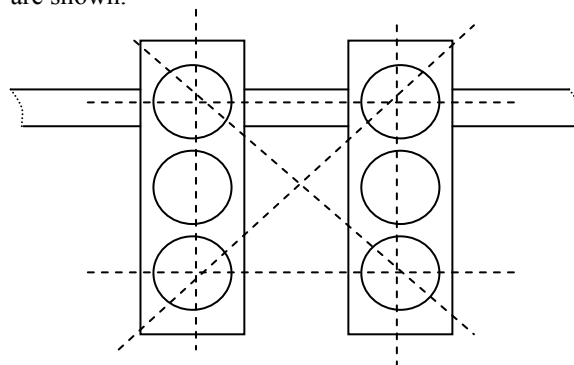


Figure 4: Image Processing Spatial Data

Light Change Architectures - Variations of an automatic system to detect and annunciate light changes are undergoing evaluation at an architectural level. The first was an aid to prompt the driver that a light has changed. Initial tests showed that when used as an aid for situational awareness the system does not have to be exact, but merely good enough to recognize a change in light status and prompt the driver to look at the lights before proceeding. For a typical driver position in an automobile at a stop light at an intersection the driver's vertical field of vision may not include the stop light. In this situation, the driver would have to periodically lean forward to view the status of the stop light as the view is blocked by the top of the vehicle. Therefore the area of interest for sensing traffic light changes is an area at the top of the windscreen plus an extension vertically to cover the field of view.

In a second variation of the system, the light change sensor information was combined with other vehicle status information. As the car comes to a stop the route guidance system will determine if the vehicle is at or in the vicinity of an intersection. Depending on the route guidance database, the system may also know whether or not there are traffic lights at the intersection. Using the vehicle's on board forward-looking radar sensor, the system will then determine if it is first in line at the intersection. Once the light changes and is detected by the light change sensor, the driver is prompted to confirm that the light has changed before proceeding.

A third version is designed to be part of a portable after-market routing device. These devices are commonly mounted to the automobile dash or the lower windscreen. If the device is standalone then it would not necessarily have access to radar data, although that is possible through interconnection within the vehicle such as in-vehicle communications. However; the portable device itself may include forward-looking radar on the rear of the unit, and it

will also have a better vertical field of vision to detect light changes. In this version, the self-contained routing unit has a built in forward-looking radar, and a forward-looking light change detector, and access to the automobile navigation information, derived dynamics, and database.

A future version of the system, portable or fixed, may be used to detect changes in the intensity of the brake lights of the vehicle ahead. In cases where the automobile is not the first in line at the traffic light this will serve to indicate to the driver that the driver ahead has taken pressure off the footbrake and will shortly accelerate. This light change indication would precede any indication of movement from forward looking radar.

CONCLUSIONS

As presented in this paper, several variations of automatic systems to signal a vehicle's intent and to detect and announce light changes are under evaluation as part of a privately funded research program. Previous research firmly supports the position that these systems and applications will incrementally but significantly improve traffic flow and throughput by providing necessary situational awareness to drivers. The benefits promise to be substantial given the growth in vehicle ownership and the limited incremental increase in road facilities planned over the near future.

Although a pre-requisite for this research, it is concluded that these systems must be non cooperative in order to achieve any type of practical implementation success. Many cooperative systems, while technically sound, are impractical from an institutional perspective and will remain in the laboratory longer, while practical standalone systems will be deployed by automobile manufacturers and third party after-market technology companies.

There are many subsystems and off-the-shelf technologies on the market that are available today for both applications of automatic signalling and traffic light detection. Initial results of this research program promise to provide practical, affordable applications which are suitable for both integrated and portable third-party automotive systems.

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