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To delegate or not to delegate: A review of control frameworks for autonomous cars

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ABSTRACT

There have been significant advances in technology and automated systems that will eventually see the use of autonomous cars as commonplace on our roads. Various systems are already available that provide the driver with different levels of decision support. This paper highlights the key human factors issues associated with the interaction between the user and an autonomous system, including assistive decision support and the delegation of authority to the automobile. The level of support offered to the driver can range from traditional automated assistance, to system generated guidance that offers advice for the driver to act upon, and even more direct action that is initiated by the system itself without driver intervention. In many of these instances the role of the driver is slowly moving towards a supervisory role within a complex system rather than one of direct control of the vehicle. Different paradigms of interaction are considered and focus is placed on the partnership that takes place between the driver and the vehicle. Drawing on the wealth of knowledge that exists within the aviation domain and research literature that examines technology partnerships within the cockpit, this paper considers important factors that will assist the automotive community to understand the underlying issues of the human and their interaction within complex systems.

1. Introduction

With increasingly congested road networks the existing road infrastructure is unsufficient at meeting the growing and future demands that will be placed on it. Alongside this is a strong desire to improve efficiency and safety. At the centre of accident causality, human error remains a primary concern and advances in autonomous systems are hailed as the harbinger of a technology that can potentially reduce road fatalities in the future.

In the scope of this paper, the term autonomous system will be defined as the quality of a technology that is able to perceive information from the environment and its ability to act upon it without human intervention.

With the advent of autonomous systems, what better way to reduce human error than by removing the human driver? The impetus behind an initiative such as this is directly related to the advances in technology that can assist in the management of the traffic infrastructure such as intelligent transport systems (ITS) or in-vehicle driver assistance systems such as advanced driver assistance systems (ADAS).

Several states in the United States (i.e. Nevada, Florida, Michigan and California) have reflected this growing appetite by passing legislation that allows the introduction of autonomous vehicles onto public highways. If we look across the current range of autonomous cars (Google, Toyota, Nissan, BMW, to name but a few) we can see they are all actively researching the integration of autonomous decision-making technologies. Although there are differences across these manufacturers in terms of their approach to integrating autonomous systems, they all have one thing in common: the driver who is ultimately responsible for the vehicle.

With the onset of smaller and cheaper sensors we have seen a migration of such technology transfer from other domains into the automotive community. For example, the development of Light Radar (LiDAR) was initially designed for uses in analysing meteorological conditions (specifically cloud density). Modern LiDAR systems have been used in unmanned ground vehicles for detecting obstacles whilst navigating. Perhaps the best-known use of this within the automotive domain is the Google 'Chauffeur' car with its recognisable spinning LiDAR sensor mounted on the roof. At the moment this technology is expensive but there are already initiatives to produce a more affordable and mainstream version of this technology that could be integrated into other cars.

LiDAR is but one of the many different sensor technologies available that could be integrated within an intelligent automotive system. Within current ADAS functions, ultrasound technology is predominantly used for parking and proximity/separation such as adaptive

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cruise control (ACC), collision warning systems (CWS) and driver awareness functions such as blindspot and intersection warning. A number of possible applications that sensors may be integrated into the vehicle are shown in Fig. 1.

With these technologies employed to assist the driver, if we assume that ADAS functions such as intelligent collision warning/avoidance are integrated into the wider traffic network, how might these forms of automation actually support drivers?

There would appear to be two key ways in which the autonomous system could interact with the user. For example, an autonomous car will be able to respond to an event or situation that is perceived by the system as a potential threat (using on-board sensors) and either advise the driver on the appropriate action to take and place authority on the driver to respond; or the car will be authorised to take action on behalf of the driver in order to avoid an accident. Both cases highlight the need for a framework of delegating authority between the user and the system so that future solutions are developed with a common user-centred perspective.

2. Automation and human performance

The implication of incorporating an element of autonomy within a system predicates the delegation of authority, by the user, to the system. That is, the user who traditionally is seen as being in control of the system and 'in-the-loop' (Wiener and Curry, 1980) accepts that the system is performing certain functions either without their full knowledge (e.g. a 'blackbox' scenario) or whilst they adopt a supervisory role. However, this can lead to 'out-of-loop' situations where the operator is not fully-engaged in the task and may have diverted their attention to other activities but then be faced with taking back control at short notice and without fully understanding the current situation.

A certain degree of transparency must exist, which Norman (1990) argues, is the operator's ability to understand the automated systems and 'see through' the system's processes. Thus, the lower the transparency, the more removed the human is from the information processing which might have serious implications for situation awareness (SA).

There are many theories of automation that suggest that the human should always have the final say in any decision involving safety (Billings, 1997; Woods, 1989; Stanton et al., 2015). Such a stance represents a user-centred approach to automation, whereby the human always has authority over the decision-making elements within the system. However, delegation of control authority has been outlined in theories of adaptive automation (Parasuraman et al., 1992; Inagaki, 2003) whereby the system is authorised to make certain decisions on behalf of the human. An existing example of this is the demonstration of automotive collision avoidance braking systems (Coelingh et al., 2010; Isermann et al., 2010).

The application of automation can be viewed in most domains as an attempt to reduce the workload burden of the operator whilst also offering a higher level of safety and efficiency. This is particularly valid in the aerospace domain, where over the last thirty years we have witnessed a revolution in automated flightdecks (Harris, 2011; Stanton et al., 2015). Of course, while there is a great deal of literature citing the benefits of increasing automation, there is evidence that highlights potential drawbacks. What we can conclude from the literature is that by increasing the level of automation in an attempt to mitigate instances of human error, it may not eliminate it altogether. In fact what we are confronted with is a different type of human error borne out of the ironies of automation (Bainbridge, 1983). Again, we can look at examples in aerospace where incidents of automation bias (Mosier et al., 1998) and automation surprise (Sarter et al., 1997) have been regarded as a confounding factor in many accidents. As a consequence, it has been argued that automation should take on tasks for the pilot rather than instead of the pilot and support, rather than take over from the pilot (Stedmon and Selcon, 1997).

For example, the tragic flight of Air France 447 in 2009 is testament to how a highly skilled flight crew can suddenly lose SA when a system is under automatic control. While cases such as these are rare, we are compelled to learn from them in order to assure that the same mistakes are not made again.

It is important to compare those piloting aircraft (who are generally highly trained and monitored, working in a sector that is closely regulated, and with technologies maintained to a high standard), operating aircraft worth millions of pounds and owned by an aviation company (a party who measures the pilot's actions in the interests of profit and safety and who themselves will be under international scrutiny) with those members of the public operating their own vehicles with differing degrees of training, responsibility and levels of maintenance for their own cars. For example, young drivers in the fast moving, congested arterial roads during rush hour, who are using vehicles close to the end of their lifecycles operate in a different context to those piloting aircraft.

The importance of providing the user with a reasonable understanding of what the system is doing (and why) is essential, especially in instances where a system failure or change in situation demands occurs with little notice for the user to engage with rectifying the situation. Much like humans, systems can fail and are fallable (Reason, 2013). Therefore it is important that we do not stand in awe of such advanced systems but rather try to optimise the relationship in a safe and effective manner.

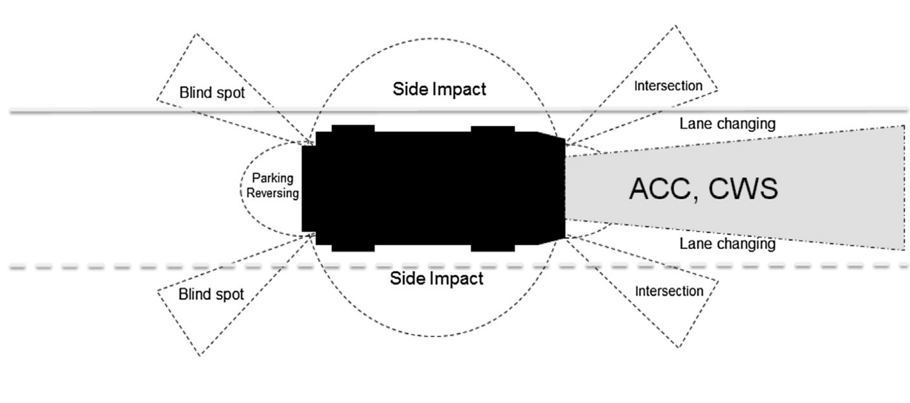

Fig. 1. Some available automotive sensor applications.