Driver Behavior Monitoring. Part I. Application to Adaptive Automation Implementation

Toshiyuki INAGAKI and Makoto ITOH

Department of Risk Engineering

University of Tsukuba, Tsukuba 305-8573 Japan

{inagaki, itoh}@risk.tsukuba.ac.jp

Abstract

This paper gives a description on a currently going MEXT supported research project, “Situation and intention recognition for risk finding and avoidance,” the aim of which is to develop a human-centered proactive safety technology that (i) detects at an early stage possible transitions of the driver’s psychological/physiological state into a risky condition that may lead to a possibly accident-prone driving condition, and (ii) provide the driver with appropriate countermeasure assistance and support in a situation-adaptive manner. Among research issues in the project, this paper discusses the need of an adaptive automation for automotive safety when driver’s intention or behavior may be inappropriate for a given traffic condition.

INTRODUCTION

It is often said that 70-80 % of the car accidents involve human errors. Some portions of those human errors stem from *mismatches* among driver’s capabilities, vehicle functionalities, and traffic environment. Controlling high-speed vehicles in a dense and dynamically changing environment is highly demanding for ordinary car drivers. Such factors sometimes assume the drivers excessive abilities for situational recognition, decision-making, and action implementation. Proactive safety technology that finds those mismatches and avoids their associated risks is thus a key to automotive safety improvements and reduction of car accidents in an essential manner. Various research projects have thus been conducted or still in progress across the globe in order to develop proactive safety technologies: See, e.g., (Akamatsu & Sakaguchi 2003; Akamatsu et al 2003; Furugori et al 2003, 2005; Witt, 2003; Amditis et al. 2005; Cacciabue & Hollnagel, 2005; Panou et al. 2005; Saad, 2005; Sakakibara & Taguchi 2005; Taguchi & Sakakibara 2005; Tango & Montanari, 2005).

This paper gives an overview on a currently going MEXT (Government of Japan) supported research project, “Situation and intention recognition for risk finding and avoidance,” the aim of which is to develop a human-centered proactive safety technology that (i) detects at an early stage possible transitions of the driver’s psychological/physiological state into a risky condition that may lead to a possibly accident-prone driving condition, and (ii) provides the driver with appropriate countermeasure assistance and support in a situation-adaptive manner. Among research issues in the project, this paper discusses the need of an adaptive automation for automotive safety when driver's intention or behavior may be inappropriate for a given traffic condition.

PROJECT OVERVIEW

Driving requires a continuous process of perception, decision, and action. Understanding of the current situation determines what action needs to be done (Hollnagel & Bye, 2000). In reality, however, drivers' situation recognition may not always be perfect. Decisions and actions that follow poor or imperfect situation recognition can never be appropriate to the given situations. It is not possible to "see" inside of a driver's mind to know whether a driver's situation recognition is correct or not. However, monitoring the driver's behaviour and traffic environment may make it be possible to guess: (a) whether the driver has lost situation awareness, (b) whether the driver's intention is inappropriate for the given situation, (c) whether the driver is inactive psychologically (e.g., due to inappropriate trust or complacency) or physiologically (e.g., due to fatigue); see, Figure 1.

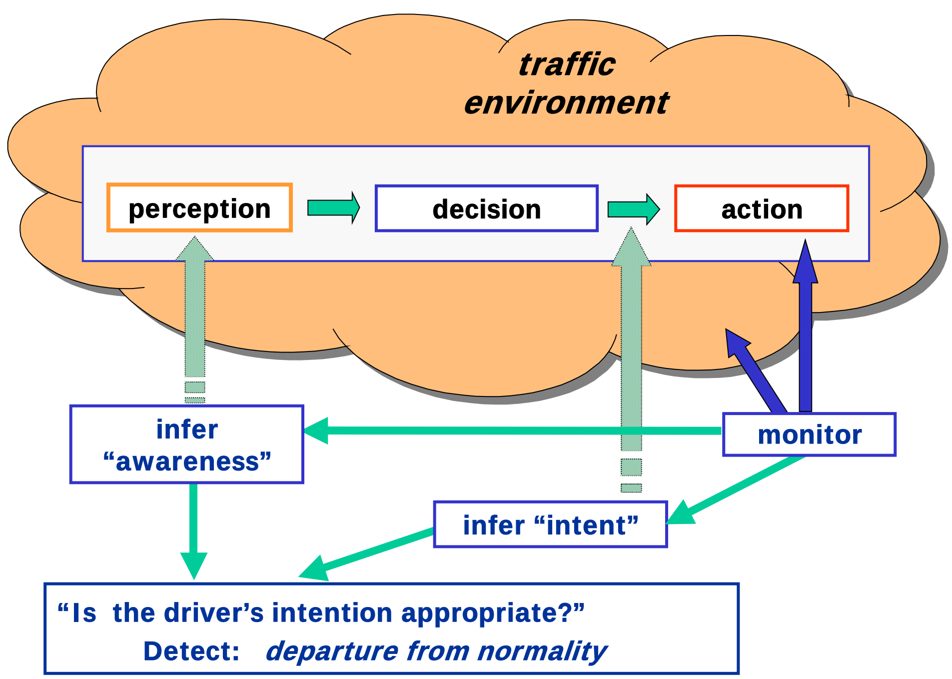

Figure 1: Inferring driver's situation recognition and associated intention

The research project, “Situation and Intention Recognition for Risk Finding and Avoidance,” was launched in 2004 under the support of the Ministry of Education, Culture, Sports, Science and Technology, Government of Japan. The aim of the project is to develop proactive safety technologies to detect mismatches among traffic situation, its recognition by a driver, intention of the driver, and to provide the driver with an appropriate assist in a situation-adaptive manner.

The research topics in the project can be categorized as follows: (1) estimation of driver’s state, (2) driver behaviour modelling, (3) intelligent information processing methods for situation recognition and visual enhancement, and (4) adaptive function allocation between drivers and automation. In (1), real-time methods are under development for detecting the driver’s inattentiveness, hypo vigilance, and complacency, which is discussed in (Itoh & Inagaki, 2006). Levels of driver’s fatigue and drowsiness are estimated also in (1) by applying a chaos theoretic method (Shiomi & Hirose, 2000) to driver’s voice in verbal communication. Driver modelling in (2) adopts a Bayesian network approach on the basis of recorded data on driver behaviors, as in the case of the Behaviour-based Human Environment Creation Technology project (Akamatsu & Sakaguchi 2003; Akamatsu et al 2003). Some mathematical and information processing methods are dealt with in (3) for machine learning and recognition of traffic environments and human vision enhancement or augmentation.

Based on analyses of a driver’s behaviour, the methods in (1) - (3) give some messages or warnings to the driver when it is determined that the driver’s situation recognition or intention may not match to a given traffic condition. If the driver responds quickly to the messages or warnings, the potential risk shall be diminished successfully. If the driver failed to accept or respond to the messages or warnings in a timely manner, on the other hand, accidental or incidental risks may grow. Research activities in (4) deal with such situations, and aim to develop an adaptive automation that can support drivers at various levels of automation.

ADAPTIVE AUTOMATION

The design decision of assigning functions to human and machine is called *function allocation*. The traditional ways of function allocation are classified into three categories: (1) *comparison allocation*, or, MABA-MABA (what “men are better at” and “what machines are better at”) approach that compares relative capabilities of humans versus machines for each function and allocates the function to the most capable agent; (2) *leftover allocation* that allocates to machines every function that can be automated, in which humans are assigned the leftover functions that cannot be automated; and (3) *economic allocation* that tries to find an allocation ensuring economical efficiency. The traditional strategies determine “who does what” and yield function allocations that are *static*: viz., once a function is allocated to an agent, the agent is responsible for the function at all times. The static function allocations are easy to implement. However, “who does what” design decisions are not sufficient, because operating environment may change as time goes by, or performance of the human may degrade gradually as a result of psychological or physiological reasons. That means, “who does what and when” considerations are needed.

Definition of adaptive automation

A scheme that modifies function allocation between human and machine dynamically depending on situations is called an *adaptive function allocation*. The adaptive function allocation assumes criteria to determine whether functions have to be reallocated, how, and when. The criteria reflect various factors, such as changes in the operating environment, loads or demands to operators, and performance of operators. The automation that operates under an adaptive function allocation is called *adaptive automation*; see, e.g., (Inagaki, 2003; Scerbo, 1996).

Adaptive automation is expected to improve comfort and safety of various human-machine systems in transportation. It is known, however, the humans working with highly intelligent and autonomous machines often suffer negative consequences of automation, such as the out-of-the-loop familiarity problem, loss of situation awareness, automation surprises. Adaptive automation may face with those undesirable consequences, if carelessly designed. Especially, decision authority over automation invocation (viz., who makes decisions concerning when and how function allocation must be altered) is one of critical design issues in adaptive automation, and discussions need to be made in a domain-dependent manner (Inagaki, 2006). Automobile is one of domains in which machine-initiated control over automation invocation may be allowed for assuring safety.

Decision authority and the levels of automation

In the discussion of decision authority, the notion of the *level of automation* (LOA) is useful. Table 1 gives an expanded version in which an LOA comes between levels 6 and 7 in the original list by Sheridan (1992). The added level, called the level 6.5, has been firstly introduced in (Inagaki, Itoh, & Moray, 1997) with two-fold objectives: (1) to avoid *automation surprises* (Sarter et al 1997) induced by automatic actions and (2) to implement actions that are indispensable to assure systems safety in emergency. When the LOA is positioned at level 6 or higher, the human may not be in command. Generally speaking, it would be desirable, philosophically and practically, that human is maintained as the final authority over the automation (Billings, 1992, 1997; Woods, 1989). However, decision authority needs to be discussed in a domain-dependent and context-specific manner. As a matter of fact, there are cases, in which automation may be given decision authority (Inagaki, 1999, 2000; Inagaki & Furukawa, 2004).

Table 1: Scales of levels of automation

1.	The computer offers no assistance; human must do it all.
2.	The computer offers a complete set of action alternatives, and
3.	narrows the selection down to a few, or
4.	suggests one, and
5.	executes that suggestion if the human approves, or
6.	allows the human a restricted time to veto before automatic execution, or
6.5	executes automatically upon telling the human what it is going to do, or
7.	executes automatically, then necessarily informs humans,
8.	informs him after execution only if he asks,
9.	informs him after execution if it, the computer, decides to.
10.	The computer decides everything and acts autonomously, ignoring the human.

After Sheridan (1992), Inagaki et al (1997), and Inagaki & Furukawa (2004).

Illustrative examples

The followings are a couple of examples of adaptive automation that shall be implemented in the "Situation and Intention Recognition for Risk Finding and Avoidance" project by incorporating methodologies developed there.

> ***Example 1:*** The driver of the host vehicle *H* wants to make a lane change, because the forward vehicle *A* drives rather slowly. The host vehicle's on-board computer that has been monitoring backward with a camera has recognized that a faster vehicle *C* is coming from behind on the left lane. At that time moment, the driver of the host vehicle, who has seen a very fast vehicle *B* almost passed him on the left, is about to steer to the left, failing to notice that vehicle *C* is approaching close (Figure 2). The on-board computer warns the driver by making the wheel either heavy to steer (*soft protection*) or impossible to steer (*hard protection*). The computer takes the steering authority from the driver partially in cases of soft protection (viz., the driver still can steer to the left) or fully in cases of hard protection.

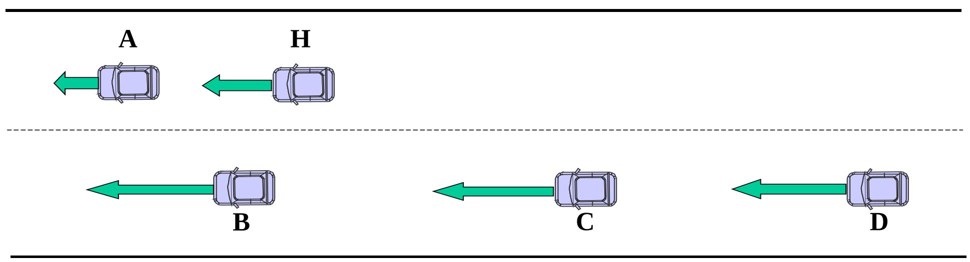

Figure 2: An example in which machine intelligence is given decision authority

The LOA for soft protection or hard protection in Example 1 is set at 6.5, because the protection function is activated immediately when the computer warns the driver. If the computer executed the protection function silently (without giving any visual or auditory warning), the LOA may be regarded as 7. Another possible design alternative may be just to warn the driver that vehicle *C* is approaching close when the driver is about to steer to the left, failing to notice vehicle *C*. The LOA in that case is set at 4. Which LOA is appropriate depends on time-criticality.

> ***Example 2***: The driver of the host vehicle *H* wants to make a lane change to the left, because the forward vehicle *A* drives rather slowly. When glancing at the rear view mirror, the driver noticed that faster vehicles, such as *C* and *D*, are coming from behind on the left lane; see, Figure 2 again. By taking several looks at the side mirror, the driver has been trying to find a precise timing to cut in. In the meantime, the on-board computer has determined that the driver might not be able to pay attention to the forward vehicle *A*, while monitoring the driver who looked away several times in a short time period. The computer then puts its emergency braking function into the armed position in preparation for a deceleration of the forward vehicle *A*. If the forward vehicle *A* does not make any deceleration before the host vehicle's driver completes a lane change, the computer will disarm the emergency braking function. If the computer detects a rapid deceleration of the forward vehicle *A* while the driver is still looking for a timing to make a lane change, the computer applies an automatic emergency brake immediately when it warns the driver.

In Example 2, the on-board computer may put its emergency braking function into the armed position in preparation for a deceleration of the forward vehicle *A*, when it has determined that the driver pays little attention to the forward vehicle *A*. The LOA of the computer's action is set at 8, because it never tells the driver voluntarily that it has put the emergency braking function into the armed position. The driver may never know the computer's action if vehicle *A* did not make any deceleration before the he or she completed a lane change. Main reasons for such a high LOA in this case are that there is no possibility for any automation surprise to occur and that "informing everything" may be sometimes annoying for the driver. The LOA is set at 6.5 for the computer's execution of automatic emergency brake upon detecting a rapid deceleration of the forward vehicle *A*. The efficacy of LOA-6.5 for such cases has been proven via discrete-event simulations (Inagaki & Furukawa, 2004; Inagaki et al 2005).

CONCLUDING REMARKS

This paper has given an overview on a currently going MEXT supported research project, "Situation and intention recognition for risk finding and avoidance," and has discussed the need of an adaptive automation for automotive safety when driver's intention or behavior may be inappropriate for a given traffic condition. The decision authority, which is one of central design issues in adaptive automation, has been described in terms of the concept of the LOA.

A series of preliminary cognitive experiments with a driving simulator have just been completed. The experiments have shown that a hard or soft protection in Example 1 and an emergency automatic brake in Example 2 contribute appreciably to improvement of automotive safety. It has been shown also in the experiments that intent communication between the driver and the automation is a key to reduce possibilities of automation surprises and to attain human's trust in automation. Even though the accident rate has been greatly reduced with the automation, subjects in the experiments did not always appreciate the automation's safety control functions when they failed to understand the intent of automation.

ACKNOWLEDGMENTS

This study was conducted as part of the government project, "Situation and Intention Recognition for Risk Finding and Avoidance" under the support of the Ministry of Education, Culture, Sports, Science and Technology, Government of Japan.

REFERENCES

Akamatsu, M., & Sakaguchi, Y. (2003). Personal fitting driver assistance system based on driving behaviour model. Proceedings of IEA2003 (CD-ROM).

Akamatsu, M., Sakaguchi, Y., & Okuwa, M. (2003). Modeling of driving behavior when approaching an intersection based on measured behavioral data on an actual road. Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting (CD-ROM).

Amiditis, A., Lentziou, Z., Polychronopoulos, A., Bolovinou, A., & Bekiaris, E. (2005). Real time traffic and environment monitoring for automotive applications. In : Macchi, L., Re, C., & Cacciabue, P.C. (eds) Proc. International workshop on modelling driver behaviour in automotive environments, 125-131.

Billings, C.E. (1992). *Human-centered aircraft automation: A concept and guidelines* (NASA Techn. Mem. 103885). NASA-Ames Research Center.

Billings, C.E. (1997). *Aviation automation – The search for a human-centered approach*. LEA.

Cacciabue, P.C. & Hollnagel, E. (2005). Modelling driving performance: A review of criteria, variables and parameters. In : Macchi, L., Re, C., & Cacciabue, P.C. (eds) Proc. International workshop on modelling driver behaviour in automotive environments, 185-196.

Furugori, S., Yoshizawa, N., Iname, C., & Miura, Y. (2003). Measurement of driver's fatigue based on driver's postural change. Proceedings of SICE Annual Conference, pp. 1138-1143.

Furugori, S., Yoshizawa, N., Iname, C., & Miura, Y. (2005). Estimation of driver fatigue by pressure distribution on seat in long term driving. Review of Automotive Engineering, 26(1), 53-58.

Hollnagel, E. & Bye, A. (2000). Principles for modeling function allocation. Int. J. Human-Computer Studies, 52, 253-265.

Inagaki, T. (1999). Situation-adaptive autonomy: Trading control of authority in human-machine systems. *Automation technology and human performance: Current research and trends* (pp.154-159). LEA.

Inagaki, T. (2000). Situation-adaptive autonomy for time-critical takeoff decisions. *International Journal of Modelling and Simulation*, 20(2), 175-180.

Inagaki, T. (2003). Adaptive automation: Sharing and trading of control. In: Hollnagel, E. (ed) Handbook of cognitive task design (pp. 147-169). LEA.

Inagaki, T. (2006). Design of human-machine interactions in light of domain-dependence of human-centered automation. Cognition, Technology and Work (in press).

Inagaki, T., & Furukawa, H. (2004). Computer simulation for the design of authority in the adaptive cruise control systems under possibility of driver's over-trust in automation. Proc. IEEE SMC Conference, 3932-3937.

Inagaki, T., Moray, N., & Itoh, M. (1997). Trust and time-criticality: Their effects on the situation-adaptive autonomy. Proc. International Symposium on Artificial Intelligence, Robotics, and Intellectual Human Activity Support for Nuclear Applications, 93-103.

Inagaki, T., Furukawa, H., & Itoh, M. (2005). Human interaction with adaptive automation: Strategies for trading of control under possibility of over-trust and complacency," Proc. HCII (Augmented Cognition) 2005 (CD-ROM).

Itoh, M. & Inagaki, T. (2006). Driver behavior modeling. Part II : Detection of driver's inattentiveness under distracting conditions. Proc. DSC-Asia/Pacific (to appear).

Panou, M., Bekiaris, E., & Papakostopoulos, V. (2005). Modeling driver behavior in EU and internationak projects. In : Macchi, L., Re, C., & Cacciabue, P.C. (eds) Proc. International workshop on modelling driver behaviour in automotive environments, 5-21.

Saad, F. (2005). Studying behavioural adaptations to new driver support systems. In : Macchi, L., Re, C., & Cacciabue, P.C. (eds) Proc. International workshop on modelling driver behaviour in automotive environments, 63-73.

Sakakibara, K. & Taguchi, T. (2005). Evaluation of driver’s state of tension. Proceedings of HCI International 2005 (CD-ROM).

Sarter, N.B., Woods, D.D., & Billings, C.E. (1997). Automation surprises. In G. Salvendy (Ed.). *Handbook of human factors and ergonomics* (2nd ed., pp. 1926-1943). Wiley.

Scerbo, M. W. (1996). Theoretical perspectives on adaptive automation. In: Parasuraman, R. & Mouloua, M. (eds) Automation and human performance (pp.37-63). LEA.

Sheridan, T. B. (1992). Telerobotics, automation, and human supervisory control. MIT Press.

Shiomi, K. & Hirose, S. (2000). Fatigue and drowsiness predictor for pilots and air traffic controllers. Proc. 45th Annual ACTA Conference, 1-4.

Taguchi, T. and Sakakibara, K. (2005). Evaluation of driver’s state of tension. Review of Automotive Engineering. 26 (2), 201-206.

Tango, F. & Montanari, R. (2005). Modeling traffic and real situations. In : Macchi, L., Re, C., & Cacciabue, P.C. (eds) Proc. International workshop on modelling driver behaviour in automotive environments, 133-147.

Witt, G.J. (2003). SAfety VEhicle(s) using adaptive interface Technology (SAVE-IT) Program. DTRS57-02-R-20003.

Woods, D. (1989). The effects of automation on human’s role: Experience from non-aviation industries. In S. Norman & H. Orlady (Eds.). *Flight deck automation: Promises and realities* (NASA CR-10036, pp.61-85). NASA-Ames Research Center.