Development of Visual Complexity Model Framework in Driving Context

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ABSTRACT

Recently, in-vehicle environments have become smart environment with advances in IT technology. The vehicle is no longer just a means of transportation but gets the nature of information system. Therefore, in order to convey more information than in the past, a variety of displays are set up in vehicle. The object of this study is to develop visual complexity model framework for evaluating system interface. To accomplish this, we reviewed the literature about complexity measures in terms of Human-Machine Interaction and analyzed the characteristics of in-vehicle environment characteristics. Then we suggest visual complexity model framework.

Keywords: Visual complexity, Human-Machine Interaction, IVIS

INTRODUCTION

The development of information technologies changes the context of driving. In-Vehicle Information System (IVIS) provides a lot of functions. As the number of function of system is increasing, various displays are used for providing drivers with information. (e.g. Cluster, Head-Up Display, Center- facia Information Display, Rear mirror display, etc.). So driver is exposed to much information. Considering visual sensory is most critical modality (Sivak, 1996), risk of accident could be increased because visual information leads to driver distraction.

According to National Highway Traffic Safety Administration (NHTSA), 25% of traffic accident happened because of driver inattention (Wang et al., 1996). Stevens and Minton (2001) reported that one of the critical factors of traffic accidents is high-tech equipment, i.e. infotainment system, navigation system, telematics system, etc. Wickens(2002) presented that increasing in-vehicle technology is the cause of traffic accidents because visual attention resource of driver is limited.

As previous research analyzed, using large amount of information doesn't only have effect on driver, also it is the cause of deterioration in driving performance (Chisholm et al., 2007; Horberry et al., 2006). Thus it is important to predict and measure accident risk. Previous studies of in-vehicle environment analyzed driver mental workload with driving task. In order to analyze the effect of non-driving task on driving performance, many variables were used, e.g. response time, missed events, lane-keeping ability, speed control (Castro, 2008). However, previous studies have mainly focused on driver workload rather than the complexity of system itself. So, it is impossible to verify whether complexity of system influence on driver perception or not. But, it is difficult to find cause and effect relationship between system and driver. Thus the object of this study is to suggest "Complexity" for analyzing effect of In-Vehicle Information Systems on driver and the framework for measuring it. Utilizing complexity, we will predict and control driver workload from parts of system being increased.

A study of complexity deals with various aspects. But, few studies analyzed Human-Machine Interaction (HMI) in the context of driving using the concept of complexity. Therefore our study includes three questions: What is visual complexity from HMI perspective? How visual complexity is explained based on theoretical basis? How do we measure the visual complexity? To answer these three questions, we analyze in-vehicle environment and driver behavior from the perspective of HMI. Then we suggest the framework for measuring visual complexity.

LITERATURE REVIEW

It is difficult to define complexity because the concept of complexity is complicated itself. Also, definitions of complexity are differentiated by purpose of analysis. Complexity stems from Latin word 'complexus' meaning entwined or twisted together. Generally speaking, complexity of certain system could be increased if more parts of system are districted or connected with each other.

Many researchers have been studied the complexity in various field of studies : information theory, general systems theory, cybernetics, non-equilibrium thermodynamics, catastrophe theory, deterministic chaos, complex adaptive systems (Heylighen, 1993). Xing and Manning(2005) also presented that complexity have been studied in many fileds, e.g. Physics, System, Mathematical science, Software engineering, Biology, Psychology.

Visual complexity also has been studied in various domain fields, such as image, web page, aesthetics etc. Olivia et al. (2004) studied perceptual dimensions of visual complexity of scenes. Michailidou et al. (2008, September) studied relationship between visual complexity and aesthetic perception. Guo et al. (2011) represented relationship between visual complexity perception and texture image. Forsythe (2009) evaluated different measures of complexity. Harper et al. (2009) analyzed relationship between use's visual perception of web page complexity and user's cognitive efforts. Lavie and Tractinsky (2004) assessed dimensions of perceived visual aesthetic of web sites.

In this way, many researchers studied on complexity depending on the characteristics of study domain. But there have been relatively few studies on visual complexity from the perspective of Human-Machine Interaction. Especially, There are also few studies on visual complexity in vehicle environment. So we use the complexity in order to analyze interaction between human and system in vehicle environment.

Characteristics of visual complexity in terms of Human-Machine Interaction (HMI)

In this study, we would define 'Visual Complexity' from a HMI perspective, especially, when driver perceive the visual information from in-vehicle display. In order to achieve this, we analyzed the characteristics of complexity in terms of system and driver.

Complexity of system in Human-Machine Interaction (HMI)

In-vehicle systems collect data about internal/external environment, vehicle condition, etc. Systems provide drivers with information on the ground of the collected data. Drivers_drive the car on the basis of this information and vehicle states are changing. These processes continue iteratively (figure 1). In these processes, drivers interact with systems through system interface. Drivers perceive the visual information through the display of system interface. Continually, drivers control the input device of system interface. So driver's perceived visual complexity is the interface complexity in terms of system.

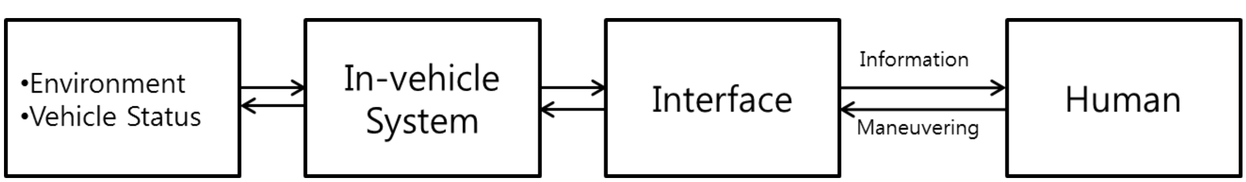

Figure 1. Process of Human-Machine Interaction in the context of driving.

The environment of in-vehicle system interaction is similar to the environment of in-aircraft system interaction. Cumming et al. (2010) suggested Human Supervisory Control complexity chain composed of Environmental complexity, Organizational complexity, Interface complexity, Cognitive complexity in Air Traffic Control Environment. According to this, interface complexity was defined "the complexity derived from controls and displays, which could include display font size, number of colors used in the display, or numbers and variety of buttons, levers, etc." In conclusion, in-vehicle interface consist of visual information displays and maneuvering areas. Based on this study, we focus on information display as domain of perceived visual complexity.

Complexity of Human behavior in Human-Machine Interaction (HMI)

Edmonds(1999) stated that complexity is meaningful relative to individual person. Moreover, information is perceived by each driver's visual information process (Mihal & Barrett, 1976). Therefore, in order to define complexity, there should be discussion of these issues. Henneman and Rouse(1986) categorized complexity as Non-Behavioral complexity or Behavioral complexity in order to emphasize interaction between human and system in terms of cognitive engineering. Non-Behavioral complexity studies include complexity interested in certain system's condition. Most studies on complexity belong to Non-Behavioral complexity, e.g. computational complexity, software complexity, physical system complexity, redundancy and complexity, subjective nature of complexity. Behavioral complexity studies include complexity interested in human's psychological-behavioral characteristics. Relatively few researchers studied Behavioral complexity. Behavioral complexity studies are divided into Perceptual complexity and Problem-solving complexity. Perspective of this study is a perceptual complexity within behavioral complexity

According to Wickens(2002), steps of Human Information Processing include Sensory processing, perception, Response selection, Response excution in order. Human allocate their attention resource to each step and use working memory. In these processes, Sensory processing and perception steps are main focus of Perceptual complexity.

Characteristics of in-vehicle environment

The definition of visual complexity of this study differs from that of web page or image studies. So it is important to consider characteristics of in-vehicle driving situation. There are two kinds of characteristics of visual display and visual search task.

First, several characteristics of in-vehicle visual display should be considered. As previously stated, there are increasing introduction of new information technology into in-vehicle environment. So there is an abundance of visual information provided to driver in vehicle environment. As a result, various visual displays are embedded in the vehicle. Different characteristics of each display have effect on visual task (Tan and Czerwinski, 2003). Also information is presented in different forms, e.g. text, icon, image, graph, etc. Diverse information formats influence Human Information processing. Especially, perception and cognition processes of visual information are different depending on information formats. . Lastly, visual displays are dynamic. Information is continuously changed with driving condition.. Xing(2004, 2005, 2007) studied the information complexity of Air Traffic Control automation displays. In-vehicle environments with advances in IT technology have become similar to in-air traffic control environment. Thus, it is also important to consider complexity in vehicle environments..

Second, characteristics of visual search task should be considered. In-vehicle situation, drivers were required to perform two or more tasks concurrently. Drivers perform additional visual task while they perform driving task at the same time. Many studies on IVIS, HUD analyzed the effect of using the system while driving task. Also there are many attributes that will affect driving such as driving experience, gender, age, others. And driving contexts also exit like a road conditions, weather, day, night, light, others. Lastly, Even minor error in driving context could become the cause of traffic accident. Therefore safety issues are first priority in driving context. The increasing complexity of in-vehicle systems leads to increase the possibility of driver's error increased. So, Complexity can be used in order to predict and to decrease the possibility of traffic accident.

RESEARCH FRAMEWORK

Visual complexity of this study includes two points of view. Visual complexity is display complexity in terms of system and is perceptual complexity in terms of driver. Besides, we will focus the complexity when drivers perform the visual task while driving context. On the basis of these perspectives, we analyze the visual complexity.

Visual complexity has been studied in a number of different fields. Among these studies, Cummings(2010) and Xing(2004, 2005, 2007) studied on complexity in similar environment of this study. Following these studies, we will suggest the factor of system, i.e. information structure attributes of in-vehicle display. Cummings(2010) revealed that general factors of complexity are size (of parts), variety (of parts), rules/interconnections (between parts). Also, Xing(2004, 2005, 2007) suggested that information complexity of Air Traffic Control(ATC) automation display composed of three factors : Quantity, Variety, Relation. Like this, Quantity, Variety and Relation are widely accepted factors of complexity. According to studies, we also used these three factors.

Quantity

First factor of visual display is Quantity. The term “Quantity” means amount of something to measure or count. Generally, an increase in the quantity means that the amount of system parts is increased. Increasing the number of parts makes relationship more complicated. This leads to increase the possibility of interaction between parts. Many previous studies use Quantity as factor of complexity. Quantity measurements of related studies are summarized in the table below (Table 1). Especially, there are two complexity studies relative to Human-Machine Interaction. Xing (2007) chose “number of fixation groups, number of functional units, amount of action cost” as quantity measurement of information complexity. Cummings et al. (2010) defined “number of displays, icons, alarms, shared control devices, shared displays, animated display features, required unit conversions, redundant displays, control devices, redundant control devices” as quantity measurement of Human-System Interface.

Quantity factors of complexity are available for measuring visual complexity in vehicle environment. As the amount of information increases, the relationship between information and information become complicated. Especially in the driving situation, drivers perceive it as complex scene. Thus, in this study, we define “Quantity” factor as the number of units of visual display. The number of text, icon, gradation, indicator is quantity measurement of in-vehicle visual display. There are positive correlation between these quantity measurement and visual complexity.

Variety

Second factor of visual complexity is Variety. The term “Variety” means that there are different aspects of parts. Generally, if system has variety, it consists of parts which are different from each other. An increase of variety in parts of system leads to increase their relationships. Variety attributes of system make to feel complex. Many previous studies use Variety as factor of complexity (Table 1). Xing (2007) defind “background color, component color, shape, size” as variety measurements of information complexity. Cummings et al. (2010) defined “variety of fonts, icons, colors, alarms, displays, control devices” as variety measurement of Human-System Interface.

Variety factors of complexity are available for measuring visual complexity in vehicle environment. Complexity of driver is different depending on type of information even though same amount of information. Thus, this study defines “Variety” factor as diversity characteristics of individual information of display. There is diversity of units of in-vehicle visual display, such as background color, component color, shape, size. There are positive correlation between these variety measurement and visual complexity.

Relation

Last factor of complexity is “Relation”. Relation means that relationship between parts and parts of system. Quantity factor and Variety factor are characteristics of individual part. But Relation factor composed of structural aspects. Relation is a key factor in many studies (Table 1). Especially, Xing (2007) uses “degree of clutter, relational complexity, number of action cost” as relation measurements of information complexity. Cummings et al. (2010) defined “clutter, distance between control devices, displays, controls” as relation measurements of Human-System Interface. According to Tullis (1983), how user perceived information from the display is determined by four characteristics, i.e. overall density, local density, grouping, layout complexity.

Relation factors of complexity are available for measuring visual complexity in vehicle environment. It is different to perceive the level of complexity depending on "relation" even though same amount of information and level of variety. Thus, we define "Relation" factor as relational characteristics of units of in-vehicle visual display. Relation factors of in-vehicle visual display are clutter and number of division.

Table 1: Related study of three factors of complexity

Factor	Study	Measurement
Quantity	Xing(2007)	Number of fixation groups, number of functional units, amount of action cost
	Kemp(1999)	Number of block
	Michailidou et al (2008)	number of images, visible links, words
	Olivia et al(2004)	Quantity of object, detail, color
	Mccabe(1976)	Difference of the total number of transitions and the total number of states
	Bieri(1955)	Number of construct, matches between the constructs
	Cummings et al. (2010a)	number of displays, information amount, number of icons, number of alarms, number of shared control devices, number of shared displays, number of animated display features, number of required unit conversions, number of redundant displays, number of control devices, number of redundant control devices
Variety	Xing(2007)	dynamic complexity
	Cummings et al. (2010a)	variety of fonts, variety of icons, variety of colors, variety of alarms, variety of displays, variety of control devices
	Michailidou et al. (2008)	variety of colors
Relation	Xing(2007)	degree of clutter, relational complexity, number of action cost
	Kemp(1999)	text to graph ratio
	Bieri(1955)	matches between the constructs
	Cummings et al. (2010a)	clutter, distance between control devices, displays, control devices and displays, controls and their associated displays

CONCLUSIONS

In conclusion, we suggest a framework for measuring visual complexity in order to evaluate in-vehicle interface. We reviewed previous study in order to analyze the complexity from the perspective of Human-Machine Interaction (HMI). First, we focus on in-vehicle visual display by analyzing in-vehicle systems. Second, we chose perceptual complexity by reviewing previous studies. For this, we define factors of complexity by analyzing previous complexity study and characteristics of in-vehicle environment. The framework composed of three factors : Quantity, Variety, Relation. This framework integrates human factors in the context of driving. We defined "Quantity" factor as the number of units of visual display, "Variety" factor as the diversity of units of in-vehicle visual display, "Relation" factor as relational characteristics of units of in-vehicle visual display.

Future study is needed to find measurement of each factor of visual complexity. Moreover, we will develop structural equation of visual complexity. This equation enables us to evaluate the n-vehicle system interface. Then we will be able to predict the driver's workload arise from in-vehicle interface.

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