A Human Factors Evaluation of the Spatial Gesture Interface for In-Vehicle Information Systems

Yishuo Liu, Zhihao Lu, and Pilsung Choe

Department of Industrial Engineering, Tsinghua University, Beijing, China
liuys@yahoo.cn, joeluk@163.com, pchoe@tsinghua.edu.cn

Abstract. The spatial gesture control system is an integrated control system, and a new hope for In-Vehicle Information Systems (IVISs). It needs lots of further research for practical use of the working systems in reality. Concept designs and evaluation standards can be investigated at the initial stage of the research. In this study, we established a usability evaluation model for the spatial gesture control system, and determinants for user satisfaction in driving have been investigated. Finally, some gesture interfaces were evaluated with a human factors experiment.

Keywords: spatial gesture control, IVISs, usability.

1 Introduction

Considering the complex computerized interior system of cars, driving is an integrated human-computer-interaction activity almost everyone gets involved every day. While driving a vehicle, the driver is performing varied tasks. These tasks can be classified into two main categories – the primary tasks and the secondary tasks.

While finishing the primary tasks depends largely on the hardware of a vehicle, the performance in finishing the secondary tasks leaves a lot work on the interface design. As the development of modern technology and entertainment, drivers have been gradually exposed to rows of buttons, knobs and touch-screens in order to control radios, CD players, GPS devices, lights, air conditioners, and even TV sets and Internet connections. All of these fancy features are joyful in using on one hand, while on the other hand, are stressful to use properly for drivers. Designers in the auto industry have been working on integrating many secondary controls into a single menu-based interactive system [1], with only the most frequent and important controls left as hard switches. The gesture control on capacitive screens has been proven a genuine success in the cell phone and tablet PC market, seems to be a revolutionary solution of the IVISs. However, it cannot be ignored that the touch-screen requires a certain level of visual attention and it might has negative impact on safety. Besides, a relative accurate position and movement of the finger(s) is often not easy in a bumpy context. Considering the requirements of visibility and reachability, a compromised position of the touch-screen may mean that the drivers must be held outstretched during operation, which might cause some level of muscle fatigue, and at the mean time, the position of the arm and fingers may obscure part of the screen [2]. Other solutions

P.L.P. Rau (Ed.): CCD/HCII 2013, Part I, LNCS 8023, pp. 313–322, 2013.

such as voice recognition and steering wheel-mounted controls are often used to supplement IVISs [3], but they have "inherent limitations without significant safety benefits" [1].

The development of depth-sense camera technology in the recent years, however, shows a new possible solution by offering the detection of location and movements in 3D-form. Spatial gestures, or the 3D-form gestures, differ from conventional notion of gestures limited on a 2D interface. And we are able to develop interfaces marked with the spatial gesture control system to interact with the systems by using hand and body gestures in 3D-form.

In this study, as an exploration to this field, we built the evaluation model of the usability of this kind of system, and conducted a small-scale test on a subset of the parameters. Along with the experiments, we also aimed to collect some intuitive spatial gestures via interviewing the subjects.

2 Determinants of User Satisfaction in Driving

To assist the design and evaluation process of the system, we need to acquire a tool to predict the performance of the specific solution under real conditions of use. That requires a modeling process and technical standards for the definition of the performance. Card, Moran, and Newell proposed a model concerning the interaction between the task, user, and computer (represents for any interactive system) would enable designers to predict system performance [4]:

Model(Task, User, Computer) → System Performance

Since usability of a system is a part, or a kind, of the system performance, we specified the model for our study as:

Model(Task, User, Computer) → System Usability

According to this model, before predicting the system usability, the essence of the specific tasks, the users' requirements, and the features of the computer, need to be further understood.

The Task

Driving is a complex, multitasking activity [5], consisting of interactions between the driver, the car, and the environment [6]. As concluded in former sections, driving task includes two major categories – primary and secondary. Hedlund, Simpson, and Mayhew listed steering, accelerating, braking, speed choice, lane choice, maneuvering in traffic, navigation to destination, and scanning for hazards as the primary driving tasks [7]. Hedlund et al. also defined the secondary tasks as all other tasks performed by the driver that are not directly related to driving [7]. Secondary tasks are not essential to successful driving, but to enhance the driving experience while addressing the driver's needs [8]. Harvey et al. further concluded that the secondary tasks are to provide information, entertainment, and a means of communication, and enhance comfort to the driver [3].

The User

There are abundant technologies, software and hardware, supporting the in-vehicle interactions. Though the advance of technology itself boosts the driving experience, it cannot be neglected that the capabilities and fitness of the human operator, as a participant of the entire system, is a source of constraint. In some literatures, the focus has transited from technology, solely, to consideration of how to integrate the technology with the human element of the interaction [9]. And in the same literature, Walker et al. identified three main driver needs: safety, efficiency and enjoyment, which are considered important by automotive manufactures related to the information and communication technologies in vehicles [9].

The user safety is defined as the capacity to avoid risk or damage to the user in operation [10]. Based on a previous test, Klauer et al. estimated that distraction caused by secondary task interaction contributed to more than 22% of all crashes and near crashes, and the distraction caused by the interaction should also be noticed and considered during the design process [11]. The distraction of an IVIS should be measured. Efficiency is defined here as the capacity of reaching the destination in an acceptable time with acceptable expense. The efficiency of IVISs is defined by the degree of whose ability of presenting clear and useful information, successful and efficient input, and monitoring of the state, thus it is determined by the design of the system and its interface [3]. As transporting is not the only requirement for driving for many people, the enjoyment of driving can be a key issue in elevating the driving experience. Enjoyment comes from comfort and satisfaction, and can be measured subjectively by evaluating user's preferences [3]. Although enjoyment doesn't affect finishing the primary driving tasks directly, it does help the process by relieving the boredom and maintaining the driver's alertness [12].

The System

Automotive manufactures have attempted to integrate secondary driving controls into a single interactive, screen-based IVIS: touch screen as the direct way, and rotary controller as the indirect way [3]. Both solutions need screens to give the feedbacks and display the statuses of the systems. The major difference is the translation between the input from the user and the reaction of the device [13]. The indirect devices have this kind of translation, while the direct devices do not. Although touch screen has a significant advantage of direct devices - easy to learn, the inherent disadvantages caused by the position of the screen remain constraint of the user's experience. The spatial gesture control interface is a brand new realization of IVISs. By applying the spatial gesture control, it is hopeful to acquire the advantages of both solutions: easy to learn, and ergonomically optimal position of the screen.

And as a kind of information systems, van der Heijden stated that the nature of information systems could be classified into utilitarian and hedonic [14]. The former category provide external value via the interaction, and the latter one is to provide self-fulfilling and the internal satisfaction, rather than instrumental value to the user [15]. Other than the difference of the two categories, previous studies also found a significant relationship between perceived enjoyment and behavioral intention to use information systems [14]. In other words, the hedonic character of an information system may help increase the users' intention to perceive the external value by using it. This would be an advantage for the spatial gesture control system, if it were generally conceived that it is more fun than conditional control.

Predicting the System Usability

Six factors have been concluded in a previous review of literature relating to IVISs on how to measure and improve the usability of these devices: dual task environment, environmental conditions, range of users, training provision, frequency of use, and uptake [3]. Combined with features of the spatial gesture control system, the independent factors of the system usability are concluded and defined as bellow:

- Dual task environment: One of the most important factors relating to the usability of IVISs was that the interaction with this system was not the driver's main task [16], and most of the time is spent performing the primary driving tasks in vehicles [17,18].
- Environmental conditions: Unlike other information devices, the IVISs are designed to use in a variety of environmental conditions. Thus the impact of the environmental factors such as light levels, sound levels, road conditions, weather, and other road users, emergency levels (e.g., rushing to a hospital for severely injured passenger), need to be considered, tested, and measured.
- Range of users: The population of potential IVISs users is very diverse in physical, intellectual, and perceptual characteristics, thus requires special consideration in the design and evaluation [3]. Two of the most important and widely studied user characteristics are age and experience. Elder drivers and novice drivers are considered as the most vulnerable group in terms of balancing the dual task environment [19,20,21].
- Uptake: This factor describes how easy to learn and to use the system by initial users. The issue of uptake is strongly related to the user's subjective experience of the system, as this will determined whether the IVIS is with usability in driving [3].
- Weighs of functions: based on the original term "frequency of use" as listed by Harvey et al. [3], the weights of functions considered both the frequency of use and the perceived importance of each functions controlled by the system.
- Perceived controllability: As resembles the physical gaming devices, the spatial gesture control interface uses user's physical movement as input. Considering the motion-sense is the foundation of this system, the perceived controllability is proposed to represent the extent to which the user perceives the system is under his or her spatial gesture control.
- Perceived enjoyment: Since enjoyment is a key user requirement of the feature of the system, the perceived enjoyment is proposed representing the extent to which the user enjoys using the system. The possible muscle fatigue and any other impact of the body movement are to be considered in this issue.
- Perceived comfort: The spatial gesture interface requires the user controlling the system via physical movement in a defined pattern. Thus the characters of the movement, such as, the range, the direction and the trajectory of the movement will have impact on the physical and mental comfort the user perceived during the process.

All of the eight factors are intermediate points for further analysis. The analysis could work as an instructive segmentation of finding qualitative measurable independent variables of the system usability.

3 Case Study: An Experiment

Lehto, Mark, and Jim Buck defined that system usability includes three aspects: efficiency, effectiveness, and satisfaction [22]. As a subset of usability, the satisfaction was our primary focus in this study. To evaluate the satisfaction via an indoor test, we arbitrarily selected three of the eight factors we mentioned above to design the experiment: perceived controllability, perceived enjoyment, and perceived comfort. The following experiment was designed to reveal the relationship between these three factors and the gesture.

Subjects

We invited 9 subjects for the test, aged from 21 to 53, and consisted of 6 male and 3 female. All of the subjects have driving license. Their driving frequency and experience are varied.

Variables: Independent and Dependent Variables

Perceived controllability, perceived enjoyment and perceived comfort were chosen as the dependent variables. Since this test was to study the relationship of the spatial gestures and users' satisfaction, the independent variables should be able to define the gestures. Thus, three factors were defined as the independent variables:

- Gesture Direction: The trajectory of a spatial gesture can be a curve, a spatial quadrilateral, etc. While a straight line is the simplest one, thus the direction of "drawing" the line might have impact in to the dependent variables. The variable had two levels (horizontal, vertical) in the experiment.
- Gesture Part: The body movement appears in various scale. To make an action to the system, the user may move fingers, wrist, elbow and shoulder. Thus the movement can be scaled by the largest joint it takes, such as, wrist-scale, and elbow-scale. We choose two levels (wrist, elbow) in our experiment.
- Task: The functions of IVIS can be sorted into several classes, while there are two basic types: the control of ON/OFF, and of UP/DOWN. The first class is to change between two statuses; the second one is to adjust among several discrete statuses (i.e. switching radio) or to control a continuous variable (i.e. the volume of the radio). In this test, we choose the control of the doom light and of the radio volume as two levels of this factor.

Therefore, the test was designed to study the impact of the three independent variables to the three dependent variables.

Experimental Design: 2^3. Full-Factorial, Within Subject Design
Each of the independent variables were given two status. The 2x2x2 factorial design was used for the experiment as shown in Fig. 1. In addition, a within-subject design was used for better comparisons with the eight treatments. That is, each subject tried all of 8 treatments. The trial order was randomized to minimize learning effects.

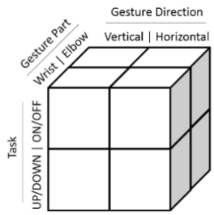

Fig. 1. The 2^3 Full-Factorial Design

Apparatus
Wizard of Oz Approach. As an integrated IVIS, it requires immediate feedback from the system and the specific design and development remain variable in several aspects, thus making it difficult and inefficient to use functional prototype in a real vehicle. For this reason, we decided to conduct the experiment with a Wizard of OZ (WOz) approach, which was first used by Gould et al. [23]. We replaced the central computer with a human operator, observed the users and controlled the related functions and feedbacks in the prototype with a computer.

The Wizard of Oz method has been used for a variety of intentions in HCI literature. Dahlbäck et al. used this method to design and collect language corpora in speech-based systems [24]. Höysniemi et al. further developed the idea of using WOz method in collecting corpora, but based on the children's body language – their intuitive gestures in an interactive physical video game [25].

Although the Wizard of Oz approach is widely reported in HCI literature, the papers contain little ethical discussion related to the method [25]. We decided to specify our reasons for the application of the WOz method as follow,

- As to summarize an instruction to the further development of the final system, we need to use a prototype that can present the features, and at the same time feasible for rapid improvement. The key point is the ability to change the functions without laborious and time-consuming coding and debugging during the study.
- Using a wizard, combined with adequate training prior to the test to ensure the experience matching our design. The responsiveness and the successful recognition rate were important for this system.
- The method, in the process, can also help us gather valuable information on the natural and intuitive body language in the specific context. There is no existing research on the body language users prefer in a vehicular context, focusing on finishing the secondary tasks on IVISs.

Previous researches applying WOz also showed other benefits. As to the possible latency brings by a human operator, Höysniemi et al. stated in their paper that they were "surprised how well the wizard was able to adapt to the children's movements and rapid gesture changes" [25] because the wizard was able to anticipate.

Experiment Setup. The experiment was held in a lab with LCD to display instructions and simulated scene, as shown in Fig. 2.

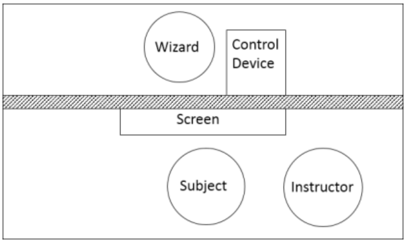

Fig. 2. Experiment Setup

Our experiment, following the WOz approach, involved a wizard, a subject, and an instructor. The wizard simulated as an integrated program, controlled the devices via a computer, observed the user's command, reacted to the user's actions, and took notes during the interviews. The instructor introduced the tasks, guided the testing and interviewed the user during and after the tests.

The experiment was conducted in two stages. After a brief introduction of the experiment, each subject was first given two tasks in the first stage: turn on and off the doom light, and turn up and down the volume of in-vehicle radio player. The subjects were required to finish each task without any instruction in order to record the natural and intuitive gestures. After a short interview and a break, came the second stage: Eight tasks were shown successively with their instructions of the specific spatial gesture we defined. After each task, the subject scored (1 to 7) the treatment and was interviewed after.

4 Results and Analysis

Eight treatments was applied to nine subjects, thus we had 72 data points. A summary of the algebra average is shown in Table 1.

After using ANOVA to analyze the interaction of the three factors, several conclusions were drawn as below.

First, for the interaction of reaction part and direction, treatments with wrist-scale movements and in the vertical direction had high score in all of the three criteria, while the combination of elbow-scale and horizontal gesture got the lowest score. Second, for the interaction of reaction direction and task, we found that there existed a preference of controlling the doom light with vertical movement and a horizontal one for the volume adjusting. Third, for the interaction of reaction part and task, all of the combinations got medium or high scores in all of the three criteria, except for the combination of controlling volume with arm, which was scored low in all the three.

Table 1. Average Score of each Treatment

Treatment	Perceived Enjoyment	Perceived Controllability	Perceived Comfort	Sum
1	4.78	5.22	5.22	15.22
2	5.11	5.33	5.44	15.89
3	4.89	5.33	5.33	15.56
4	4.89	5.44	5.56	15.89
5	5.33	5.67	5.67	16.67
6	5.22	5.11	4.78	15.11
7	5.78	6.11	5.89	17.78
8	5.78	6.00	6.00	17.78

Other than the pair interaction, we analyzed the means and variance of each treatment's impact on the three factors as shown in Fig. 3.

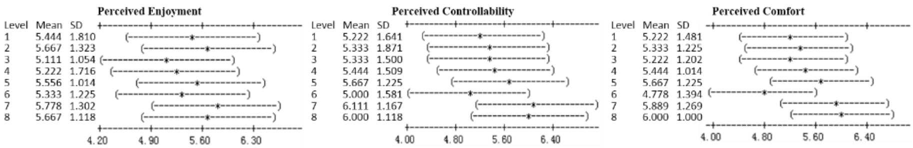

Fig. 3. Mean and Variance of the three Factors

The difference was not significant in perceived enjoyment. All of the nine subjects expressed their preference of the spatial gesture interface to the existing buttons and knobs. But treatment 6 (adjusting the volume with arm waving up/down) was significantly inferior to others in aspects of perceived controllability and perceived comfort. Subjects complained that this treatment was against their intuition in a degree, and the range of this function was too large considering the frequency. The difference among other treatments were not significant enough. But the situation might change for on-road test, concerning the frequency of use and the dual task environment.

Combined with the interview, we found that there were other preferences of performing a spatial gesture:

- Near the object: users preferred performing near to the object they were controlling, i.e. perform a gesture near the doom light to turn it on or off, near the radio to adjust the volume.
- Resemble the existing movement: during the first stage of the test and the interview after, subjects presented significant intention of using gestures that resemble the current movement. For example, some subjects preferred to adjust the volume by turning their hand clockwise/anti-clockwise as controlling with an invisible knob.
- Smaller the better: there is a strong preference of smaller scale gesture, especially for frequent functions, such as adjusting volume and choosing songs.

These preferences are important instructions in designing the standard set of controlling gestures in the future.

5 Discussion and Conclusions

In this study, we modeled the evaluation of the spatial gesture control interface, revealed the relationship of the gesture and user satisfaction via an experiment, and collected the intuitive gestures of two in-vehicle functions in the interview. However, there were several limitations of our study. First, we listed eight intermediate points for the evaluation of the spatial gesture interface, and three measurable independent variables of a subset of user satisfaction, but the entire group of quantitative measurable variables needs to be further defined and specified, as well as the interaction of the variables and the eight points. Second, we used a WOz approach in this study, but we believe a full-scale functional prototype would be better for further evaluation of this interface, considering the factors such as, dual task environment and environmental conditions. Third, a set of standard spatial gestures needs to be defined to make the interface fully-functional, and thus larger scale interview and experiments are in need. Although there still remains a lot for further research, the spatial gesture interface is a promising advance in the intersection of HCI and automobile research, as well as the future of IVIS.

References

1. Pickering, C.A., Burnham, K.J., Richardson, M.J.: A review of automotive human machine interface technologies and techniques to reduce driver distraction. In: 2007 2nd Institution of Engineering and Technology International Conference on System Safety, IET (2007)
2. Taveira, A.D., Choi, S.D.: Review study of computer input devices and older users. Intl. Journal of Human–Computer Interaction 25(5), 455–474 (2009)
3. Harvey, C., et al.: In-Vehicle Information System to Meet the Needs of Drivers (2011)
4. Card, S.K., Moran, T.P., Newell, A. (eds.): The psychology of human-computer interaction. CRC (1986)
5. Lee, J.D., Young, K.L., Regan, M.A.: Defining driver distraction (2009)
6. Rakotonirainy, A., Tay, R.: In-vehicle ambient intelligent transport systems (i-vaits): Towards an integrated research. In: Proceedings of the 7th International IEEE Conference on Intelligent Transportation Systems, pp. 648–651. IEEE (2004)
7. Hedlund, J., Simpson, H., Mayhew, D.: Summary of proceedings and recommendations. In: International Conference of Distracted Driving (2006)
8. Engström, J., et al.: Meeting the challenges of future automotive HMI design: an overview of the AIDE integrated project. In: 4th European Congress on Intelligent Transportation Systems and Services, Budapest, Hungary (2004)
9. Walker, G.H., Stanton, N.A., Young, M.S.: Hierarchical task analysis of driving: A new research tool. Contemporary Ergonomics, 435–440 (2001)
10. Alonso-Ríos, D., et al.: Usability: a critical analysis and a taxonomy. International Journal of Human-Computer Interaction 26(1), 53–74 (2009)
11. Klauer, S.G., Dingus, T.A., Neale, V.L., Sudweeks, J., Ramsey, D.J.: The impact of driver inattention on near-crash/crash risk: An analysis using the 100-car naturalistic driving study data. No. HS-810 594 (2006)

12. Bayly, M., Young, K.L., Regan, M.A.: 12 Sources of Distraction inside the Vehicle and Their Effects on Driving Performance. Driver Distraction: Theory, Effects, and Mitigation 191 (2008)
13. Dul, J., Weerdmeester, B.: Ergonomics for beginners: a quick reference guide. CRC (2008)
14. Van der Heijden, H.: User acceptance of hedonic information systems. MIS Quarterly, 695–704 (2004)
15. Lin, H.-H., Wang, Y.-S., Chou, C.-H.: Hedonic and utilitarian motivations for physical game systems use behavior. International Journal of Human-Computer Interaction 28(7), 445–455 (2012)
16. Fastrez, P., Haué, J.-B.: Designing and evaluating driver support systems with the user in mind. International Journal of Human-Computer Studies 66(3), 125–131 (2008)
17. Ji, Y.G., Jin, B.S.: Development of the conceptual prototype for haptic interface on the telematics system. International Journal of Human-Computer Interaction 26(1), 22–52 (2009)
18. Stanton, N.A., Young, M.S.: Vehicle automation and driving performance. Ergonomics 41(7), 1014–1028 (1998)
19. Baldwin, C.L.: Designing in-vehicle technologies for older drivers: Application of sensory-cognitive interaction theory. Theoretical Issues in Ergonomics Science 3(4), 307–329 (2002)
20. Herriotts, P.: Identification of vehicle design requirements for older drivers. Applied Ergonomics 36(3), 255–262 (2005)
21. Stevens, A., et al.: Design guidelines for safety of in-vehicle information systems. TRL Limited (2002)
22. Lehto, M.R., Buck, J.: Introduction to human factors and ergonomics for engineers. CRC (2007)
23. Gould, J.D., Conti, J., Hovanyecz, T.: Composing letters with a simulated listening typewriter. Communications of the ACM 26(4), 295–308 (1983)
24. Dahlbäck, N., Jönsson, A., Ahrenberg, L.: Wizard of Oz studies—why and how. Knowledge-based Systems 6(4), 258–266 (1993)
25. Hoysniemi, J., Hamalainen, P., Turkki, L.: Wizard of Oz prototyping of computer vision based action games for children. In: Interaction Design And Children: Proceeding of the 2004 Conference on Interaction Design and Children: Building a Community, vol. 1(03) (2004)
26. Harvey, C., et al.: Context of use as a factor in determining the usability of in-vehicle devices. Theoretical Issues in Ergonomics Science 12(4), 318–338 (2011)