WheelSense: Enabling Tangible Gestures on the Steering Wheel for In-Car Natural Interaction

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Abstract. This paper presents WheelSense, a system for non-distracting and natural interaction with the In-Vehicle Information and communication System (IVIS). WheelSense embeds pressure sensors in the steering wheel in order to detect tangible gestures that the driver can perform on its surface. In this application, the driver can interact by means of four gestures that have been designed to allow the execution of secondary tasks without leaving the hands from the steering wheel. Thus, the proposed interface aims at minimizing the distraction of the driver from the primary task. Eight users tested the proposed system in an evaluation composed of three phases: gesture recognition test, gesture recognition test while driving in a simulated environment and usability questionnaire. The results show that the accuracy rate is 87% and 82% while driving. The system usability scale scored 84 points out of 100.

Keywords: Tangible gestures, smart steering wheel, in-vehicle user interface, in-car natural interaction.

1 Introduction

Every year more and more people spend a considerable part of their life in cars. Recent statistics demonstrated that the average Swiss resident drove 23.8 km per day in 2010 [1]; in U.K., the average motorist spent 10 hours per week in his car [2]. For this reason, car makers are trying to make this “in-vehicle life” more enjoying, by equipping the car with various In-Vehicle Infotainment Systems (IVISs). All these systems need to be controlled by the car inhabitants and the common approach is to position most of these controls in the central dash board, in order to make them accessible also to the passenger. Typical approaches make use of knobs and buttons, but over the years many car makers have replaced these primordial systems with touchscreens, or advanced haptic controls like the BMW i-Drive [3]. When control systems are placed in the central dashboard, the driver has to leave one hand from the steering wheel and the eye gaze from the road. According to Bach et al. [4], most cases of general withdrawal of attention are caused by the loss of visual perception, often because of

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eyes-off-the-road distraction. Indeed, moving the controls on the steering wheel allows the driver to avoid a consistent source of distraction. This is already a common practice for car makers, which offer, since several years, levers and buttons on the steering wheel to control the infotainment system and other electronic appliances in the car. However, the exponential growth of controls in the car cannot be supported only by buttons and knobs placed over or next to the steering wheel. In fact, these forms of interaction often cannot be adapted to dynamic content shown on digital screens [5]. Moreover, the arrangement of physical buttons is fixed and the space for mechanical input is limited [6]. In order to improve the car-living experience, many researchers are investigating interaction modalities that could be more natural and engaging, e.g., gestural interaction [7]. While free-hand gestures could be troublesome for the driver, gestures performed on the steering wheel appear as a safer natural interaction approach [8].

While most researchers focused on performing gestures on a touchscreen integrated in the center of the wheel [9], we explore gestures performed on the external ring as first theorized by Wolf et al. in [10]. This exploration takes into account modern theories on tangible gesture interaction which brings advantages from both tangible and gestural interaction [11]. The WheelSense system provides a novel interface based on tangible gestures performed on the steering wheel allowing the user to safely and naturally interact with the IVIS while driving.

In this paper, we analyze related work in Section 2. Then, we discuss the interaction and the gestures proposed for the control of the IVIS in Section 3. Section 4 depicts the architecture of the system, while the tests performed on eight users are presented in Section 5. In Section, 6 we make a brief discussion about our findings and we conclude the paper in Section 7 presenting also the future work.

2 Related Work

In the last years, several researchers have explored gestural interaction in the car as an alternative and more natural interface to control IVIS. Recently, Riener has affirmed that "in-vehicle gestural interfaces are easy to use and increase safety by reducing visual demand on the driver" [8]. So far, different approaches have been proposed. Although free-hand gestures could seem unsafe, Rahman et al. developed a system to control multimedia devices through free-hand gestures recognized by a 3D camera [12]. A safer approach was proposed by Endres et al.: instead of gesturing in the air with the whole hand, the user can move just a finger, with the hand still on the steering wheel [13]. In this case, finger gestures were recognized through electric field sensing. A similar system was exploited by Riener and Wintersberger near the gearshift to control a mouse cursor on an in-car screen [5]. In order to assess if gestures could improve and make safer the interaction with the IVIS, Bach et al. compared touch gestures on a touch screen to a classic tactile system and a touch Graphical User Interface [14]. Even if they did not noticed improvement on driving task errors, the study evidenced that touch gestures were able to lower the visual demand. These results suggest that gestural interaction could be safer than other approaches if interaction designers manage to reduce the cognitive load with appropriate feedbacks, and proposing gestures that are easy to remember. Bach et al.'s test was performed on a touchscreen integrated in the dashboard. Several researchers investigated a different position for a touch screen, i.e., integrated in the steering wheel. Pfleging et al. [9] integrated a standard tablet in the steering wheel combining touch gestures with speech commands. Döring et al. used a rear mounted projector to display information inside a steering wheel with a Plexiglas core and a camera to detect gestures performed with the thumbs on its surface [6]. While the SpeeT system [9] required detaching the hand from the steering wheel, Döring et al.'s system grants the possibility to make gestures while still grasping the external ring, which is required by the primary task.

The importance of keeping "eyes on the road and hands on the wheel" was stressed also by Gonzalez et al., [15] who proposed a text input method based on small thumb gestures on a small touchpad mounted on the wheel external ring. As an alternative approach for text input, Murer et al. explored the use of buttons on the rear of the steering wheel [16].

The analysis of the related work showed that many researchers aimed at displacing the interaction from the central dashboard to the steering wheel, granting as much as possible hand contact with the steering wheel. The design of gestures to be performed while grasping an object has been analyzed in depth by Wolf et al. [10], who described a large set of microgestures associated to a cylindrical grasp, i.e., the typical grasp for the steering wheel.

3 Design of Tangible Gesture Interaction on the Steering Wheel

Tangible gesture interaction has been recently defined by Hoven and Mazalek as "the use of physical devices for facilitating, supporting, enhancing, or tracking gestures people make for digital interaction purposes" [11]. Tangible gesture interaction still belongs to the broader field of tangible interaction, conjugating its most important property, i.e., physicality, and the communicative role of gestures. In this project, the physicality is brought by the steering wheel, which can be seen as a tangible interface not only for the driver's primary task [17], benefiting of the direct manipulation of the car behavior and of the haptic feedback from the road, but also for secondary tasks. In this section, we analyze the design of gestures performed on the steering wheel for the interaction with the IVIS discussing both their physics and semantics.

Wolf et al. analyzed from an ergonomic point of view the possibility to use microgestures on the steering wheel to perform secondary tasks while driving [10]. In particular, they identified some gestures that are particularly easy to perform while the driver holds the steering wheel. Following Wolf et al.'s analysis for the palm grasp, we chose three gestures: tapping with the index and dragging fingers around the wheel (in both directions). A fourth gesture, squeezing, has been chosen even if it was not considered in the Wolf et al.'s analysis. In fact, this latter gesture requires minimal effort and cognitive load for the user as well as the other three gestures. Several systems used squeezing as interaction modality with objects; Fishkin et al. showed in

[18] some advantages of the squeeze gesture, for example the possibility to perform a squeeze without moving the hand from the object, which indeed is very useful while driving.

In order to facilitate remembering the four chosen gestures, embodied metaphors [19] have been used to associate their corresponding functions for controlling the infotainment system. The driver can start performing the tap gesture on the steering wheel in order to make some music: indeed, a single tap with the index is interpreted by the system as turning on the music. Dragging up and down the fingers on the steering wheel allows browsing up and down in the playlist. Squeeze is used to turn off the music, which intuitively binds closing the hand to closing the music player. The four gestures are shown in Fig. 1.

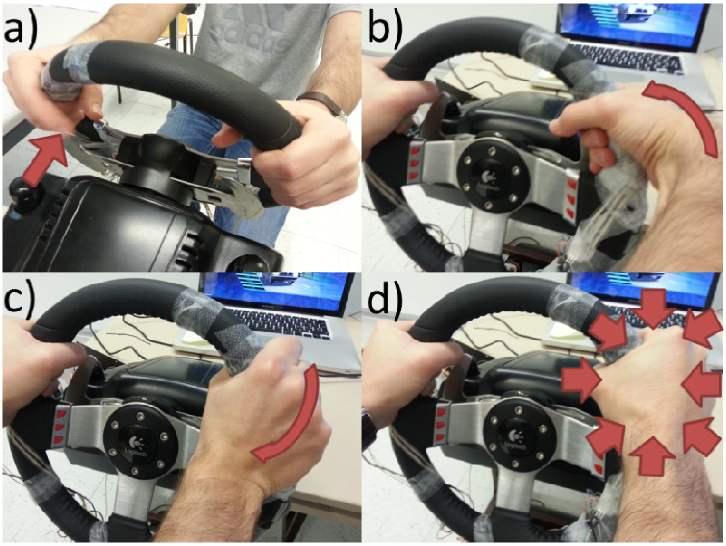

Fig. 1. Representation of the four gestures: a) tap, b) dragging up, c) dragging down, d) squeeze

The design of a gestural interface requires a proper feedback in order to acknowledge the user on the result of the command. Tangible gesture interaction on the steering wheel involves doing an intensive use of haptic senses for the driver. Gestures are designed to be as intuitive as possible, without need of visual attention on the interface. Thus, it could be given as an opportune practice to convey the feedback to the user on the same haptic channel, using vibration motors or tactile displays [20]. However, as stressed from Bach et al. [4], there is a risk of increased distraction if the secondary task competes on the perceptual resources required by the primary task. Indeed, haptic feedback coming from the road and perceived through the steering wheel has an important role in the driving task. As suggested by Wickens and Hollands [21], the perceptual resources needed for the secondary task can be distributed over other senses. Moreover, we avoided tactile cues that could help the driver to detect sensors positions for two main reasons: first, we would like to maintain the surface of the steering wheel as smooth as possible, in order to avoid pain for the user during the test session; secondly, we would like to let users forget about the underlying technology, making the interaction as intuitive as possible.

In our application, we exploit the auditory feedback generated by the media player: tap and squeeze can be easily detected respectively by the presence or absence of the music. Dragging gestures can be identified with a change of the song: in the case of a playlist, the dragging up gesture is acknowledged by the music of a new song (next track), while the dragging down gesture corresponds to a song already listened (previous track). Obviously, the purpose of the application, i.e. listening to music, ensures that the auditory channel is not disturbed, thus the feedback is effective. In case of doubt, or for further information about the song, the user can still look at the screen on the central dashboard.

4 System Architecture

The sensing system implemented in the first prototype is based on five Tekscan FlexiForce sensors with a range of 0-1 lb [22]. They are connected to an Arduino Duemilanove board that converts signals to the digital domain and sends measured data to a PC for further elaboration through a wired serial connection. Data are acquired with a rate of 50 Hz. We augmented a Logitech G27 Racing Wheel with four sensors for the right hand and one sensor for the left hand. The sensors placement on the steering wheel is depicted in Fig. 2. Sensor 1 is placed to recognize the tap gesture with the index finger. In a relaxed position, the hand generally covers the three other sensors. The wrist flexion and the wrist extension performed for the dragging up and down gestures uncover respectively Sensors 3 and Sensor 4. Sensor 5 is used to segment gestures with the left hand in order to minimize false positives during the execution of the primary task: the driver squeezes the left hand while gestures are performed with the right hand. We placed the 5 pressure sensors in the specific regions of the external ring to be compliant with the hands position suggested by the Swiss driving school manual [23].

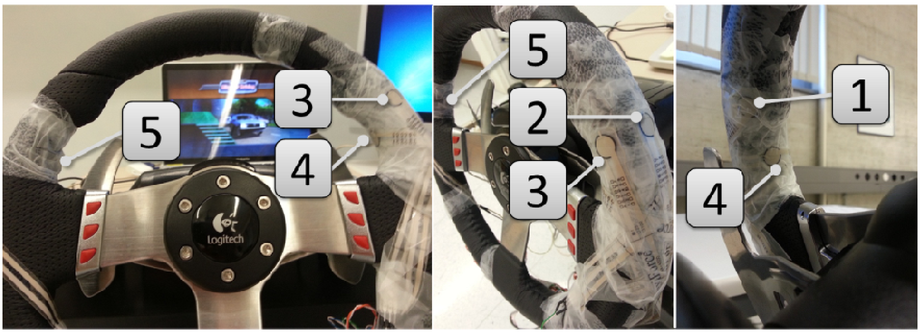

Fig. 2. The five FlexiForce sensors placement

The raw data are elaborated using the ARAMIS Framework [24], which allows a fast implementation of a recognition system through chainable services. First, gestures of the right hand are segmented setting a threshold on the left hand sensor. Afterwards, the segmented data are used as input for a Hidden Markov Model (HMM) classifier. The HMM classifier was configured with 4 hidden states with forward topology and implementing the Baum-Welch algorithm to find the unknown parameters. The data supplied to the HMM classifier are modeled as temporal signals (as depicted in Fig. 3). The whole architecture of the WheelSense system is reported in Fig. 4.

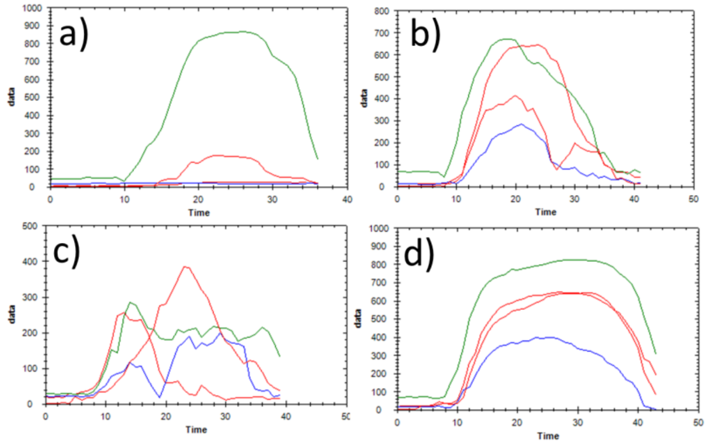

Fig. 3. Representation of the temporal signal associated to the four gestures: a) is tap, b) is dragging up, c) is dragging down and d) is squeeze

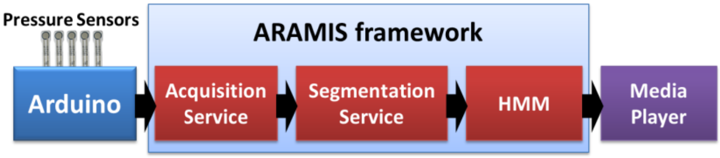

Fig. 4. Block diagram of the WheelSense system architecture

5 Evaluation

The evaluation was composed of three phases: the gesture recognition accuracy test, the gesture recognition accuracy calculated while the user was driving using a simulator and the usability questionnaire. Eight users (six males and two females, aged 25 - 31) participated to this evaluation. The setup, depicted in Fig. 5, is composed by a laptop that executes the recognition task and the City Car Driving Simulator version 1.2 [25]. The monitor on the right shows the results of the classification and it was used by the experiment supervisor.

Fig. 5. A user participating at the evaluation

5.1 Gesture Recognition Accuracy

During the first part of the evaluation process, the users were asked to perform 40 times each gesture while the PC was recording for a total of 160 gestures. The order of the gesture to be performed was chosen randomly and the user was guided by a graphical interface. The user was requested to rest at half of the recording phase. We applied the 10-fold cross-validation test on the recorded data. The resulting average accuracy is 87% and standard deviation was 17%.

5.2 Gesture Recognition Accuracy While Driving

Using the data recorded during the first phase, we trained the HMM classifier. Then, we asked to every user to drive using the City Car Driving simulator and to interact with the IVIS through the gestural interface. In this case, the gestures were used to control a music player with the gesture-function association explained in Section 3. We requested the gestures that the user had to perform; he/she had to remain focused on the driving task and to perform the gesture only when he/she was feeling confident, that means when the user evaluated the maneuver as not dangerous. The total number of gestures that each user had to perform during the driving simulation was 40 (10 per type of gesture). The average accuracy was 82% and the standard deviation among users was 16%. In fact, during the experience, we noticed a high variability between the users. The confusion matrix is reported in Table 1.

Table 1. Confusion matrix of the second phase of the evaluation: gesture recognition accuracy while driving

	Up	**Down**	**Squeeze**	**Tap**
Up	**64**	9	3	4
Down	4	**69**	1	6
Squeeze	9	4	**64**	2
Tap	7	4	4	**65**

5.3 Usability

After the second phase, we asked to the users to fill a System Usability Scale questionnaire (SUS) [26]. We calculated three factors from the SUS: the overall usability, perceived usability and the learnability. The overall usability (calculated following the standard procedure) scored 84 points out of 100 (standard deviation: 13); the perceived usability scored 82 points out of 100 (standard deviation: 12); the learnability scored 91 points out of 100 (standard deviation: 17). We calculated the last two factors as suggested by Lewis and Sauro in [27].

6 Discussion

The two performance evaluations showed a high variability among users, which affected also the results of the usability evaluation. This high variability could be explained with the different hands position of the users during the interaction. In some cases, the left hand was not always positioned over the pressure sensors, which decreased consistently the quality and the strength of the acquired signals. Variations could also occur over time: for example, in one case, the system confused several times a squeeze with a dragging up gesture, because the user was not pressing anymore on Sensor 1 (see Fig. 1). This suggests that a robust system should be difficult to achieve without taking into account the changes in the behavior of user's gestures. An adaptive learning approach could be implemented in order to avoid this issue.

7 Conclusion and Future Work

This paper presented WheelSense: a novel interface based on tangible gestures performed on the steering wheel. The proposed interaction modality allows the user to safely and naturally manage the IVIS while driving. We presented also the design of four tangible gestures: tap, dragging up, dragging down and squeeze. Gestures are used to control the media player, thus the auditory feedback is generally sufficient to avoid eye-off-the-road distraction. The evaluation of the WheelSense system assessed the accuracy being equal to 87%. We performed the evaluation of the same configuration during a simulated driving experience and WheelSense scored 82% of recognition accuracy. The system usability scale assessed the system score as 84 points.

As future work, we plan to integrate automatic segmentation and we will conduct some evaluation tests in order to compare the performances between the two different approaches: automatic segmentation versus manual segmentation. Moreover, we will implement an adaptive machine learning approach for the classifier.

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References

1. Swiss average utilization of transport means in 2010. Swiss Federation (March 2013), `http://www.bfs.admin.ch/bfs/portal/fr/index/themen/11/07/01/01/unterwegszeiten/01.html`
2. Britons spend more time driving than socialising. The Telegraph (March 2013), `http://www.telegraph.co.uk/motoring/news/8287098/Britons-spend-more-time-driving-than-socialising.html`
3. Niedermaier, B., Durach, S., Eckstein, L., Keinath, A.: The new BMW iDrive – applied processes and methods to assure high usability. In: Duffy, V.G. (ed.) ICDHM 2009. LNCS, vol. 5620, pp. 443–452. Springer, Heidelberg (2009)
4. Bach, K.M., Jæger, M.G., Skov, M.B., Thomassen, N.G.: Interacting with in-vehicle systems: understanding, measuring, and evaluating attention. In: Proc. of BCS-HCI 2009, pp. 453–462 (2009)
5. Riener, A., Wintersberger, P.: Natural, intuitive finger based input as substitution for traditional vehicle control. In: Proceedings of AutomotiveUI 2011, pp. 33–34 (2011)
6. Döring, T., Kern, D., Marshall, P., Pfeiffer, M., Schöning, J., Gruhn, V., Schmidt, A.: Gestural interaction on the steering wheel: reducing the visual demand. In: Proceedings of the 2011 Annual Conference on Human Factors in Computing Systems, pp. 483–492 (2011)
7. Riener, A.: Gestural Interaction in Vehicular Applications. Computer, 42–47 (2012)
8. Carrino, F., Carrino, S., Caon, M., Angelini, L., Khaled, O.A., Mugellini, E.: In-Vehicle Natural Interaction Based on Electromyography. In: Proc. of AutomotiveUI 2012, pp. 1–3 (2012)
9. Pfleging, B., Schneegass, S., Schmidt, A.: Multimodal Interaction in the Car - Combining Speech and Gestures on the Steering Wheel. In: Proc. of AutomotiveUI 2011, pp. 155–162 (2011)
10. Wolf, K., Naumann, A., Rohs, M., Müller, J.: A taxonomy of microinteractions: Defining microgestures based on ergonomic and scenario-dependent requirements. In: Campos, P., Graham, N., Jorge, J., Nunes, N., Palanque, P., Winckler, M. (eds.) INTERACT 2011, Part I. LNCS, vol. 6946, pp. 559–575. Springer, Heidelberg (2011)
11. van den Hoven, E., Mazalek, A.: Grasping gestures: Gesturing with physical artifacts. Artificial Intelligence for Engineering Design, Analysis and Manufacturing 25(03), 255–271 (2011)
12. Rahman, A., Saboune, J., El Saddik, A.: Motion-path based in car gesture control of the multimedia devices. In: Proc. of DIVANet 2011, pp. 69–76 (2011)
13. Endres, C., Schwartz, T., Christian, M.: Geremin: 2D Microgestures for Drivers Based on Electric Field Sensing". In: Proc. of IUI 2011, pp. 327–330 (2011)
14. Bach, K.M., Jaeger, M.G., Skov, M.B., Thomassen, N.G.: You can touch, but you can't look: interacting with in-vehicle systems. In: Proceeding of the 26th Annual SIGCHI Conference on Human Factors in Computing Systems, pp. 1139–1148 (2008)

15. González, I.E., Wobbrock, J.O., Chau, D.H., Faulring, A., Myers, B.A.: Eyes on the road, hands on the wheel: thumb-based interaction techniques for input on steering wheels. In: Proceedings of Graphics Interface 2007, pp. 95–102 (2007)
16. Murer, M., Wilfinger, D., Meschtscherjakov, A., Osswald, S., Tscheligi, M.: Exploring the Back of the Steering Wheel: Text Input with Hands on the Wheel and Eyes on the Road. In: Proc. of AutomotiveUI 2012, pp. 117–120 (2012)
17. Fishkin, K.P., Moran, T.P., Harrison, B.L.: Embodied User Interfaces: Towards Invisible User Interfaces. In: Proc. of the IFIP Seventh Working Conference on Engineering for Human-Computer Interaction, pp. 1–18 (1999)
18. Fishkin, K.P., Gujar, A., Mochon, C., Want, R.: Squeeze Me, Hold Me, Tilt Me! An Exploration of Manipulative User Interfaces. In: Proc. CHI 1998, pp. 17–24 (1998)
19. Bakker, S., Antle, A.N., Van Den Hoven, E.: Embodied metaphors in tangible interaction design. In: Personal and Ubiquitous Computing (2011)
20. Kyung, K.U., Park, J.S.: Ubi-Pen: Development of a Compact Tactile Display Module and Its Application to a Haptic Stylus. In: Proc. of the Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, pp. 109–114 (2007)
21. Wickens, C.D., Hollands, J.G.: Engineering Psychology and Human. Prentice Hall (2000)
22. Tekscan FlexiForce (March 2013), `http://www.tekscan.com/flexible-force-sensors`
23. Teaching manual for the formation and examination of driving instructors, Manuel d'enseignement pour la formation et l'examen des moniteurs de conduite, Département fédéral de justice et police (March 2013), `http://www.asa.ch/media/archive1/Shop/Ausbildungsunterlagen/gratis/Leitfaden_Fahrlehrer_Fachgruppe_7_f.pdf`
24. Carrino, S., Péclat, A., Mugellini, E., Abou Khaled, O., Ingold, R.: Humans and smart environments. In: Proceedings of the 13th International Conference on Multimodal Interfaces, ICMI 2011, p. 105 (2011)
25. Multisoft, City Car Driving Simulator (March 2013), `http://citycardriving.com/`
26. Brooke, J.: SUS: A Quick and Dirty Usability Scale. In: Usability Evaluation in Industry, pp. 189–194 (1996)
27. Lewis, J.R., Sauro, J.: The factor structure of the system usability scale. In: Kurosu, M. (ed.) HCD 2009. LNCS, vol. 5619, pp. 94–103. Springer, Heidelberg (2009)