A Synopsis of Input Modalities for In-Vehicle Infotainment and Consumption of Interactive Media

Laura-Bianca Bilius
MintViz Lab | MANSiD Research Center
University Ştefan cel Mare of Suceava
Suceava 720229, Romania
laura.bilius@usm.ro

Radu-Daniel Vatavu
MintViz Lab | MANSiD Research Center
University Ştefan cel Mare of Suceava
Suceava 720229, Romania
radu.vatavu@usm.ro

ABSTRACT

Connected vehicles collect and share data by communicating with road infrastructure, with each other, the web, IoT systems, and with their occupants' personal devices. Part of this data is presented to drivers via a multitude of interactive devices and systems. Thus, one challenge that arises in such a complex environment is effective and safe operation of the various interactive systems, *e.g.*, the in-vehicle infotainment (IVI). In this paper, we present a synopsis of input modalities from the literature of automotive user interfaces (AutoUIs) for media consumption inside connected vehicles.

CCS CONCEPTS

• **Human-centered computing → Interaction techniques**; **Interaction paradigms**.

KEYWORDS

Interactive media; In-vehicle infotainment; Voice; Gesture; Multimodal input; Automotive UIs.

ACM Reference Format:
Laura-Bianca Bilius and Radu-Daniel Vatavu. 2020. A Synopsis of Input Modalities for In-Vehicle Infotainment and Consumption of Interactive Media. In *ACM International Conference on Interactive Media Experiences (IMX '20), June 17–19, 2020, Cornella, Barcelona, Spain.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3391614.3399400

1 INTRODUCTION

The future envisaged for the automotive industry with ubiquitous electric, smart, connected, and autonomous vehicles also pictures a vision of new interactive systems, applications, user interfaces, and media experiences for the in-vehicle environment. According to Arce-Plevnik *et al.* [11], a connected car exchanges data with other vehicles and its surroundings via local networks, Wi-Fi, and other built-in communications systems and sensors. The richness of information delivery modalities and the amount of content available for consumption inside connected vehicles [5, 6, 26, 28, 39, 66, 69] are aspects that need to be carefully examined for safe driving, *e.g.*, "*driving a modern car requires the user's full attention and performing a group of concurrent tasks*" [28] and "*the effects of driver distraction ... significantly affect all aspects of situation awareness*" [66]. In this context, it is worthwhile to examine new interaction techniques for automotive user interfaces (AutoUIs) that do not put additional demands on the driver's visual and cognitive attention, among which gesture [20, 28, 30, 35, 45], voice [7, 34, 60, 78, 88], and multimodal input [8, 18, 46, 50, 61]. In this paper, we present a synopsis of such input modalities for in-vehicle media consumption.

IMX '20, June 17–19, 2020, Cornella, Barcelona, Spain

ACM ISBN 978-1-4503-7976-2/20/06.
https://doi.org/10.1145/3391614.3399400

1.1 In-Vehicle Media Consumption and IMX

Media consumption in the specific environment of connected cars is a new topic and challenge for the IMX/TVX community which, traditionally, has focused on video/TV and user experience (the ACM TVX conference organized between 2014 and 2019, *e.g.* [29]) and on interactive TV (the EuroITV conference organized until 2013, *e.g.* [48]). The infotainment systems of connected cars have evolved considerably, providing advanced navigation and entertainment features to drivers and passengers alike. New input modalities, such as gestures and voice, have been increasingly studied for in-vehicle interactions with results presented at CHI and AutomotiveUI. Furthermore, the environment of the car itself has been recently described as a specific kind of a smart environment [65], which connects smart vehicles with the large body of work on smart environments [64] and ambient media [51, 52]. In this context, drawing the attention of the IMX community to the state-of-the-art in interactive media consumption inside smart, connected vehicles is both worthwhile and timely. This paper represents such an attempt.

2 METHOD

To identify references regarding voice and gesture input for in-vehicle interactions, we ran the query `"(gesture OR voice) AND (car or vehicle)"` on the titles of papers from the ACM DL and IEEE Xplore. We obtained 53 results for ACM DL and 79 for IEEE Xplore, which we analyzed according to the following criteria: (1) *input modality* (gesture, voice, multimodal); (2) type of *contribution* (system, recognition method for user input, and interaction technique; the latter includes user studies to evaluate established interaction techniques or end-user elicitation studies to inform AutoUI designs); (3) type of *content* that is controlled or *media* that is consumed (*e.g.*, map interaction and navigation, radio control, interaction with the in-vehicle infotainment system, etc.).

3 GESTURE INPUT

Table 1 enumerates prior work, identified by our queries, about recognition techniques for gestures performed inside the vehicle, design and engineering of systems and applications employing gesture input, and interaction techniques based on gestures to control car functions and to consume digital content inside the vehicle. End-user gesture elicitation studies [87], in which participants' preferences for gesture commands are collected and analyzed for consensus [82, 83], have been popular to inform the design of gesture-based AutoUIs [1, 14, 22, 25, 37, 43, 45]. For example, Weidner and Broll [85] elicited input commands for generic tasks (*e.g.*, select, move, rotate) and identified four interaction paradigms: real-indirect (*i.e.*, users manipulate a virtual object without touching it), real-direct (the virtual object is touched), proxy (users manipulate an imagined object), and non-gestural (interaction performed with other modalities). Other studies have addressed gesture input on the steering wheel [9, 10, 30, 35, 40, 86]. For example, the participants from Angelini *et al.*'s [9] study preferred tapping, swiping, and applying pressure on the steering wheel to perform "next," "previous," "volume up/down," "select," and "back;" Burnett *et al.* [15] reported preferences for swipe gestures due to their short execution time, which reduces the need for drivers to take their eyes off the road during gesture articulation; and Häuslschmid *et al.* [30] reported preferences for both mid-air input and gestures on the steering wheel. Other work proposed guidelines to inform the design of gesture-based interaction techniques inside the vehicle. For example, the spatial volume available for mid-air gesture articulation can be specified by the triangle defined by the steering wheel, rear mirror, and gearshift [56]; feedback provided for mid-air gesture input reduces distraction [66–68]; and peripheral visual feedback improves the user experience of gesture input [59].

4 VOICE INPUT

Voice input is convenient for in-vehicle interactions because it allows drivers to keep their hands on the steering wheel and eyes on the road. Table 2 enumerates prior work, identified by our queries, that focused on recognizing voice commands inside the vehicle, design and engineering of in-vehicle systems employing voice input, and voice-based interaction techniques. Voice recognition is less effective in noisy environments, for which noise reduction strategies [74] and guidelines for effective voice input have been proposed [32]. Also, specific techniques have been introduced to improve the recognition accuracy of voice input for in-vehicle interactions, *e.g.*, audio-visual voice activity detection, wavelet analysis, and blind source separation [23, 31, 36]; see Table 2 for more references and examples. A diversity of voice input systems have been proposed in the scientific literature for authentication in smart cars [27], access to the car manual by drivers [7], or for controlling specific car functions, such as the audio system [79, 80], navigation [41], and voice-based dialing for managing phone calls [24]. Other applications addressed control of personal devices, such as smartphones [13, 16] and smartwatches [12, 78]. Regarding the latter, Tombeng *et al.* [78] proposed a car control system using voice commands mediated by the smartwatch to lock/unlock the car, control the windows, and to start/stop the engine. Previous work found voice input effective even with short glances toward the controlled system [55, 88]. A study examining the distraction of text entry methods reported that voice input was less demanding compared to keyboard input and handwriting, and the time during which the driver's eyes were off the road was significantly shorter [34]. Another comparative study evaluated three types of voice-based AutoUIs and found that text prompts on a cluster display were more efficient compared to alternatives involving a central display and a conventional voice input system [91].

5 MULTIMODAL INPUT

Compared to unimodal input, multimodal techniques offer flexibility for effective interaction with a system under a large variety of contexts of use. Table 3 enumerates prior work on recognition methods, interaction techniques, and systems and applications implementing multimodal AutoUIs identified by our queries. One observation is that multimodal AutoUIs for in-vehicle interactions are considerably fewer compared to unimodal input (*i.e.*, 5 references compared to 52 for gesture input and 19 for voice input). For instance, Pfleging *et al.* [50] found that conventional buttons were preferred by their participants to gesture and voice input, the latter being perceived slower. In that study, voice commands were employed to specify the in-vehicle device or system to control (*e.g.*, mirror, window) and gestures were used to effect various functions (*e.g.*, move up and down, left and right); see [50] for details. Angelini *et al.* [8] reported participants' preferences for mid-air gesture and voice commands over touch input, since the former required less or no contact with the controlled system. Detjen *et al.* [18] considered voice input preferable to gesture commands, and recommended the use of gestures when there is noise in the vehicle, music is playing, or during conversations. Other researchers considered that alternative input modalities are needed according to the driving context, *e.g.*, specific situations on the road [61]. In this regard, Neßelrath *et al.* [46] described a prototype for controlling the car lights and windows with eye-gaze, micro gestures, and voice input.

6 CONCLUSION

Our examination of the scientific literature on in-vehicle input revealed the benefits of multiple modalities to interact with in-vehicle systems, such as the infotainment system, and to facilitate media consumption while driving or traveling by car. Gesture input was found intuitive, comfortable, and effective by prior work [19, 28, 38, 45, 47, 63, 73, 85], while voice commands useful for drivers to keep their eyes on the road and hands on the steering wheel [32, 34, 55]; and multimodal input [18, 46, 61] is useful for drivers to switch between input modalities [57]. We found only few instances of multimodal AutoUIs in the literature, which represents an opportunity for more work in this direction, including running comparative evaluations of alternative I/O modalities [81]. Fusing input from multiple sensors, both built-in in the vehicle and in personal smart devices [12], is another interesting direction for future work. We hope that our synopsis of the scientific literature regarding in-vehicle interaction will be useful to IMX researchers and practitioners interested in input techniques for media consumption inside smart vehicle environments.

ACKNOWLEDGMENTS

This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI-UEFISCDI, PN-III-P1-1.2-PCCDI-2017-0917 (21PCCDI/2018), within PNCDI III.

Table 1: A synopsis of prior work addressing gesture input inside the vehicle.

Reference	Main contribution: System	Main contribution: Recognition method	Main contribution: Interaction technique	Controlled car functions, devices, systems, digital content and media
Lin (2019) [37]	-	-	✓	Adjusting vehicle dynamics
Rahman et al. (2011) [53]	-	✓	-	Media playback system
Shakeri et al. (2017a) [66]	-	-	✓	VW and BMW AutoUI
Shakeri et al. (2017b) [68]	-	-	✓	Infotainment system[2]
Riener et al. (2013) [56]	-	-	✓	Flashlight, windows, washer, AC, emails, phone calls, radio, music
Shakeri et al. (2018) [67]	-	-	✓	n/a[1]
Ohn-Bar et al. (2012) [47]	-	✓	-	Infotainment system
Weidner and Broll (2019) [85]	-	-	✓	S3D displays
May et al. (2014) [44]	-	-	✓	Common car functions
Alpern and Minardo (2003) [6]	✓	-	-	Entertainment tasks, *e.g.*, find a song, adjust volume, search presets
May et al. (2017) [45]	-	-	✓	Menu navigation
Sterkenburg et al. (2017) [73]	✓	-	-	Menu navigation
Roider and Gross (2018) [58]	-	✓	-	Car functions[2]
Sterkenburg et al. (2016) [72]	✓	-	-	Audio file control, menu navigation
Angelini et al. (2014) [9]	-	-	✓	Music, traffic alerts, phone calls
Werner (2014) [86]	-	-	✓	Radio, MP3 player, phone calls, fan, brightness, temperature[2]
Ahmad et al. (2014) [2]	-	✓	-	Infotainment system[2]
FakhrHosseini et al. (2017) [21]	✓	-	-	n/a[1]
Lee et al. (2015) [35]	✓	-	-	Radio, MP3 player, air conditioning, heater
Burnett et al. (2013) [15]	-	-	✓	Music, air conditioning, navigation, radio, phone calls, fan control
Ecker et al. (2009) [19]	✓	-	-	Navigation, contacts, entertainment
Gable et al. (2014) [25]	-	-	✓	In-vehicle technologies[2]
Ecker et al. (2010) [20]	-	-	✓	Navigation, contacts, entertainment
Hessam et al. (2017) [28]	-	-	✓	AC, engine, windows, beam light, wipe windshield, flasher, radio, calls, music
May et al. (2016) [43]	-	-	✓	Menu navigation for infotainment
Mahr et al. (2011) [40]	-	-	✓	Car windows, air conditioning, radio, seat heating
Angelini et al. (2013) [10]	-	✓	-	Stereo audio
Fariman et al. (2016) [22]	-	-	✓	Air conditioning
Ahmad et al. (2018) [1]	-	-	✓	Media and contacts
Brand et al. (2016) [14]	-	-	✓	Head-Up Display
Kim and Choi (2019) [33]	-	✓	-	n/a[1]
Roider and Raab (2018) [59]	-	-	✓	n/a[1]
Sauras-Perez et al. (2014) [63]	-	-	✓	Music player
Mahetalia et al. (2018) [39]	-	✓	-	Infotainment system[2]
Häuslschmid et al. (2015) [30]	-	-	✓	Music player
Smith et al. (2018) [71]	✓	-	-	Phone and music player
Shen et al. (2017) [70]	-	✓	-	Electronic devices
Tarvekar (2018) [75]	-	✓	-	Touch-less car interface[2]
Parada-Loira et al. (2014) [49]	✓	-	-	Infotainment system (music player)
Wu and Trivedi (2006) [89]	✓	-	-	Safety study and driving assistant system[2]
Ye et al. (2018) [90]	-	✓	-	Infotainment system (music player)
Verma and Choudhary (2018) [84]	-	✓	-	Picture navigation, music/menu control and mobile phones
Deo et al. (2016) [17]	-	✓	-	n/a[1]
Sachara et al. (2017) [62]	-	✓	-	Navigation (media and maps), contacts, phone, climate
Ahmad et al. (2016) [4]	✓	-	-	Interactive displays[2]
Ahmad et al. (2014) [3]	✓	-	-	Interactive displays[2]
Tateno et al. (2019) [76]	-	✓	-	In-car devices[2]
Zobl et al. (2003) [92]	-	✓	-	Navigation system, multimedia and communication devices
Tewari et al. ([n.d.]) [77]	-	✓	-	n/a[1]
Raja et al. (2018) [54]	✓	-	-	Personal assistant[2]
Manawadu et al. (2016) [42]	-	-	✓	Route selection, parking, speed, turning, overtaking, merging, lane changing
Ma and Du (2017) [38]	-	-	✓	Music player

[1]Functions not specified (*e.g.*, gesture recognition experiment); [2]Proposal only, functions were not implemented into an actual system.

REFERENCES

[1] B. I. Ahmad, C. Hare, H. Singh, A. Shabani, B. Lindsay, L. Skrypchuk, P. Langdon, and S. Godsill. 2018. Selection Facilitation Schemes for Predictive Touch with Mid-Air Pointing Gestures in Automotive Displays. In *AutomotiveUI '18*. ACM.

[2] B. I. Ahmad, P. M. Langdon, S. J. Godsill, R. Hardy, E. Dias, and L. Skrypchuk. 2014. Interactive Displays in Vehicles: Improving Usability with a Pointing Gesture Tracker and Bayesian Intent Predictors. In *AutomotiveUI '14*. ACM, 1–8.

[3] B. I. Ahmad, J. Murphy, P. M. Langdon, and S. J. Godsill. 2014. Filtering perturbed in-vehicle pointing gesture trajectories: Improving the reliability of intent inference. In *WMLSP '14*. 1–6. https://doi.org/10.1109/MLSP.2014.6958860

[4] B. I. Ahmad, J. K. Murphy, P. M. Langdon, S. J. Godsill, R. Hardy, and L. Skrypchuk. 2016. Intent Inference for Hand Pointing Gesture-Based Interactions in Vehicles. *IEEE T. Cybernetics* 46, 4 (2016). https://doi.org/10.1109/TCYB.2015.2417053

[5] A. Aiordăchioae, R.-D. Vatavu, and D.-M. Popovici. 2019. A Design Space for Vehicular Lifelogging to Support Creation of Digital Content in Connected Cars. In *EICS '19*. ACM. https://doi.org/10.1145/3319499.3328234

[6] M. Alpern and K. Minardo. 2003. Developing a Car Gesture Interface for Use as a Secondary Task. In *CHI EA '03*. ACM, New York, NY, USA, 932–933. https://doi.org/10.1145/765891.766078

[7] I. Alvarez, A. Martin Hammond, J. Dunbar, J. Taiber, D.-M. Wilson, and J. E. Gilbert. 2010. Voice Interfaced Vehicle User Help. In *AutomotiveUI '10*. ACM, 42–49. https://doi.org/10.1145/1969773.1969782

[8] L. Angelini, J. Baumgartner, F. Carrino, S. Carrino, M. Caon, O. A. Khaled, J. Sauer, D. Lalanne, E. Mugellini, and A. Sonderegger. 2016. A Comparison of Three Interaction Modalities in the Car: Gestures, Voice and Touch. In *IHM '16*.

[9] L. Angelini, F. Carrino, S. Carrino, M. Caon, O.A. Khaled, J. Baumgartner, A. Sonderegger, D. Lalanne, and E. Mugellini. 2014. Gesturing on the Steering Wheel: A User-Elicited Taxonomy.

[10] L. Angelini, F. Carrino, S. Carrino, M. Caon, D. Lalanne, O. A. Khaled, and E. Mugellini. 2013. Opportunistic Synergy: A Classifier Fusion Engine for Micro-Gesture Recognition. In *AutomotiveUI '13*. 8. https://doi.org/10.1145/2516540.2516563

[11] L. Arce-Plevnik, A. Cohen, and T. Shor. 2016. IoT in Automotive Industry: Connecting Cars. *Nanotechnology and Nanosensors* (04 2016).

[12] L.-B. Bilius. 2020. A Smartwatch-based User Interface for In-Vehicle Interactions. In *DAS '20*.

[13] I. Bourmeyster, J. Chetoni, S. Cucchi, N. Griggio, A. Guido, G. Moroni, A. Riccio, M. Stanzani, and F. Valente. 1996. Voice controlled mobile phone for car environment.

Table 2: A synopsis of prior work addressing voice input inside the vehicle.

Reference	Main contribution: System	Main contribution: Recognition method	Main contribution: Interaction technique	Controlled car functions, devices, systems, digital content and media
Alvarez et al. (2010) [7]	✓	-	-	Vehicle manual
Kim et al. (2019) [32]	-	✓	-	Infotainment system: play music, navigation
Wong et al. (2019) [88]	-	-	✓	Driving instructions (turn left, slow down), request traffic info
Reimer et al. (2014) [55]	-	-	✓	Radio, navigation
Roider et al. (2018) [60]	-	-	✓	Navigation, phone calls
Kujala and Grahn (2017) [34]	-	-	✓	Find addresses and contact information, play music
Tamoto and Itou (2019) [74]	-	✓	-	Voice-based authentication
Khan et al. (2017) [31]	-	✓	-	Car functions (start, stop car), navigation, wipers, radio[2]
Tsurufuji et al. (1991b) [80]	✓	-	-	Car audio system
Fissore et al. (1992) [24]	✓	-	-	Voice dialing
Bourmeyster et al. (1996) [13]	✓	-	-	Control of the mobile phone (personal agenda)
Zheng et al. (2008) [91]	-	-	✓	Radio, CD player, navigation, phone calls, climate control
Hassan et al. (1993) [27]	✓	-	-	Security system
Chung and Chen (2001) [16]	✓	-	-	Application of car cellular phone[2]
Manabe and Imamura (2018) [41]	✓	-	-	Navigation
Tombeng et al. (2018) [78]	✓	-	-	Engine, car lock, car windows
Faubel et al. (2011) [23]	-	✓	-	n/a[1]
Lei et al. (2019) [36]	-	✓	-	n/a[1]

[1]Functions not specified (*e.g.*, voice recognition experiment); [2]Proposal only, functions were not implemented into an actual system.

Table 3: A synopsis of prior work addressing multimodal input inside the vehicle.

Reference	Main contribution: System	Main contribution: Recognition method	Main contribution: Interaction technique	Controlled car functions, devices, systems, digital content and media
Pfleging et al. (2012) [50]	-	-	✓	Driver seat, wipers, mirrors, windows, head-up display, air vent, cruise control
Detjen et al. (2019) [18]	-	-	✓	Parking, lane changing, start straight, hold stop-line, hold side-strip, turn left and right
Angelini et al. (2016) [8]	-	-	✓	Music player, phone calls, vocal assistant, reminders
Roider et al. (2017) [61]	-	-	✓	Contacts, navigation, system settings
Neßelrath et al. (2016) [46]	✓	-	-	Car lights, windows

In *ESP '96*. 1–4. https://ieeexplore.ieee.org/document/7082870

[14] D. Brand, K. Büchele, and A. Meschtscherjakov. 2016. Pointing at the HUD: Gesture Interaction Using a Leap Motion. In *AutomotiveUI '16 Adjunct*. ACM, New York, NY, USA, 167–172. https://doi.org/10.1145/3004323.3004343

[15] G. Burnett, E. Crundall, D. Large, G. Lawson, and L. Skrypchuk. 2013. A Study of Unidirectional Swipe Gestures on In-Vehicle Touch Screens. In *AutomotiveUI '13*. ACM, 22–29. https://doi.org/10.1145/2516540.2516545

[16] C.-J. Chung and W.-Y. Chen. 2001. Low complexity voice recognition in car environment. In *SPAWC '01*. 380–383. https://doi.org/10.1109/SPAWC.2001.923931

[17] N. Deo, A. Rangesh, and M. Trivedi. 2016. In-vehicle Hand Gesture Recognition using Hidden Markov models. In *ITSC '16*. 2179–2184. https://doi.org/10.1109/ITSC.2016.7795908

[18] H. Detjen, S. Faltaous, S. Geisler, and S. Schneegass. 2019. User-Defined Voice and Mid-Air Gesture Commands for Maneuver-Based Interventions in Automated Vehicles. In *MuC '19*. 8. https://doi.org/10.1145/3340764.3340798

[19] R. Ecker, V. Broy, A. Butz, and A. De Luca. 2009. PieTouch: A Direct Touch Gesture Interface for Interacting with in-Vehicle Information Systems. In *MobileHCI '09*. ACM. https://doi.org/10.1145/1613858.1613887

[20] R. Ecker, V. Broy, K. Hertzschuch, and A. Butz. 2010. Visual Cues Supporting Direct Touch Gesture Interaction with In-Vehicle Information Systems. In *AutomotiveUI '10*. ACM, 80–87. https://doi.org/10.1145/1969773.1969788

[21] M. FakhrHosseini, J. Sterkenburg, S. Landry, J. Ryan, and M. Jeon. 2017. Design Process of Sonically-Enhanced Air Gesture Controls in Vehicles. In *AutomotiveUI '17*. https://doi.org/10.1145/3131726.3131874

[22] H. J. Fariman, H. J. Alyamani, M. Kavakli, and L. Hamey. 2016. Designing a User-Defined Gesture Vocabulary for an in-Vehicle Climate Control System. In *OzCHI '16*. ACM, 391–395. https://doi.org/10.1145/3010915.3010955

[23] F. Faubel, M. Georges, K. Kumatani, A. Bruhn, and D. Klakow. 2011. Improving hands-free speech recognition in a car through audio-visual voice activity detection. In *2011 Joint Work. on Hands-free Speech Comm. and Microphone Arrays*.

[24] L. Fissore, P. Laface, and P. Ruscitti. 1992. HMM modeling for speaker independent voice dialing in car environment. In *ASSP '92*. 249–252 vol.1. https://doi.org/10.1109/ICASSP.1992.225925

[25] T. M. Gable, K. R. May, and B. N. Walker. 2014. Applying Popular Usability Heuristics to Gesture Interaction in the Vehicle. In *Adjunct AutomotiveUI '14*. ACM, New York, NY, USA, 1–7. https://doi.org/10.1145/2667239.2667298

[26] B.-F. Gheran and R.-D. Vatavu. 2020. From Controls on the Steering Wheel to Controls on the Finger: Using Smart Rings for In-Vehicle Interactions. In *DIS '20 Companion*. https://doi.org/10.1145/3393914.3395851

[27] M. H. Hassan, W. S. Beardslee, and T. K. Arnold. 1993. Voice recognition digital cipher lock for smart vehicles. In *MSCS '93*. 352–355 vol.1. https://doi.org/10.1109/MWSCAS.1993.343037

[28] J. F. Hessam, M. Zancanaro, M. Kavakli, and M. Billinghurst. 2017. Towards Optimization of Mid-Air Gestures for in-Vehicle Interactions. In *OZCHI '17*. ACM, NY, USA, 126–134. https://doi.org/10.1145/3152771.3152785

[29] J. Hook, P. Stenton, M. F. Ursu, G. Schofield, and R.-D. Vatavu. 2019. Welcome From the ACM TVX 2019 Chairs. In *TVX '19*. ACM, New York, NY, USA. https://dl.acm.org/doi/proceedings/10.1145/3317697

[30] R. Häuslschmid, B. Menrad, and A. Butz. 2015. Freehand vs. micro gestures in the car: Driving performance and user experience. In *3DUI '15*. 159–160. https://doi.org/10.1109/3DUI.2015.7131749

[31] S. Khan, H. Akmal, I. Ali, and N. Naeem. 2017. Efficient and unique learning of in-car voice control for engineering education. In *INMIC '17*. 1–6. https://doi.org/10.1109/INMIC.2017.8289467

[32] J. Kim, M. Jeong, and S. C. Lee. 2019. Why Did This Voice Agent Not Understand Me?": Error Recovery Strategy for in-Vehicle Voice User Interface. In *AutomotiveUI '19*. ACM, 146–150. https://doi.org/10.1145/3349263.3351513

[33] K. Kim and J. Choi. 2019. Passengers' Gesture Recognition Model in Self-driving Vehicles : Gesture Recognition Model of the Passengers' Obstruction of the Vision of the Driver. In *ICCCS '19*. 239–242. https://doi.org/10.1109/CCOMS.2019.8821649

[34] T. Kujala and H. Grahn. 2017. Visual Distraction Effects of In-Car Text Entry Methods: Comparing Keyboard, Handwriting and Voice Recognition. In *AutomotiveUI '17*. ACM, 1–10. https://doi.org/10.1145/3122986.3122987

[35] S. H. Lee, S.-O. Yoon, and J. H. Shin. 2015. On-Wheel Finger Gesture Control for in-Vehicle Systems on Central Consoles. In *AutomotiveUI '15 Adjunct*. ACM, New York, NY, USA, 94–99. https://doi.org/10.1145/2809730.2809739

[36] P. Lei, M. Chen, and J. Wang. 2019. Speech enhancement for in-vehicle voice control systems using wavelet analysis and blind source separation. *IET Intelligent Transport Systems* 13, 4 (2019), 693–702. https://doi.org/10.1049/iet-its.2018.5094

[37] H. Lin. 2019. Using Passenger Elicitation for Developing Gesture Design Guidelines for Adjusting Highly Automated Vehicle Dynamics. In *DIS 2019 Companion*. ACM, New York, NY, USA, 97–100. https://doi.org/10.1145/3301019.3324878

[38] J. Ma and Y. Du. 2017. Study on the evaluation method of in-vehicle gesture control. In *ICCSSE '17*. 145–148. https://doi.org/10.1109/CCSSE.2017.8087912

[39] J. Mahetalia, R. Mehta, S. Varudandi, and K. Samdani. 2018. A Comparative Study on Gesture Recognition Systems for Car Infotainment Systems. In *SCAN '18*. 1–7. https://doi.org/10.1109/ICSCAN.2018.8541236

[40] A. Mahr, C. Endres, C. Müller, and T. Schneeberger. 2011. Determining Human-Centered Parameters of Ergonomic Micro-Gesture Interaction for Drivers Using the Theater Approach. In *AutomotiveUI '11*.

[41] Y. Manabe and T. Imamura. 2018. Construction of a Voice Direction Database for the Destination Input Interface of Autonomous Vehicles. In *SMC '18*. 813–818. https://doi.org/10.1109/SMC.2018.00146

[42] U. E. Manawadu, M. Kamezaki, M. Ishikawa, T. Kawano, and S. Sugano. 2016. A hand gesture based driver-vehicle interface to control lateral and longitudinal motions of an autonomous vehicle. In *SMC '16*. https://doi.org/10.1109/SMC.2016.7844497

[43] K. May, T. M. Gable, X. Wu, R. R. Sardesai, and B. N. Walker. 2016. Choosing the Right Air Gesture: Impacts of Menu Length and Air Gesture Type on Driver Workload. In *AutomotiveUI '16 Adj.* 6. https://doi.org/10.1145/3004323.3004330

[44] K. R. May, T. M. Gable, and B. N. Walker. 2014. A Multimodal Air Gesture Interface for In Vehicle Menu Navigation. In *Adjunct AutomotiveUI '14*. ACM, New York, NY, USA, 1–6. https://doi.org/10.1145/2667239.2667280

[45] K. R. May, T. M. Gable, and B. N. Walker. 2017. Designing an In-Vehicle Air Gesture Set Using Elicitation Methods. In *AutomotiveUI '17*. ACM, New York, NY, USA, 74–83. https://doi.org/10.1145/3122986.3123015

[46] R. Neßelrath, M. M. Moniri, and M. Feld. 2016. Combining Speech, Gaze, and Micro-gestures for the Multimodal Control of In-Car Functions. In *IE '16*. 190–193. https://doi.org/10.1109/IE.2016.42

[47] E. Ohn-Bar, C. Tran, and M. Trivedi. 2012. Hand Gesture-Based Visual User Interface for Infotainment. In *AutomotiveUI '12*. ACM, New York, NY, USA, 111–115. https://doi.org/10.1145/2390256.2390274

[48] P. Paolini, P. Cremonesi, G. Lekakos, and M. Obrist. 2013. Chairs' Welcome. In *EuroITV '13*. ACM, New York, NY, USA.

[49] F. Parada-Loira, E. González-Agulla, and J. L. Alba-Castro. 2014. Hand gestures to control infotainment equipment in cars. In *IVS '14*. 1–6. https://doi.org/10.1109/IVS.2014.6856614

[50] B. Pfleging, S. Schneegass, and A. Schmidt. 2012. Multimodal Interaction in the Car: Combining Speech and Gestures on the Steering Wheel. In *AutomotiveUI '12*. ACM, 155–162. https://doi.org/10.1145/2390256.2390282

[51] B. Pogorelc, A. Lugmayr, B. Stockleben, R.-D. Vatavu, N. Tahmasebi, E. Serral, E. Stojmenova, B. Imperl, T. Risse, G. Zenz, and M. Gams. 2013. Ambient Bloom: New Business, Content, Design and Models to Increase the Semantic Ambient Media Experience. *Multimedia Tools and Applications* 66, 1 (2013), 7–32. http://dx.doi.org/10.1007/s11042-012-1228-4

[52] B. Pogorelc, R.-D. Vatavu, A. Lugmayr, B. Stockleben, T. Risse, J. Kaario, E.C. Lomonaco, and M. Gams. 2012. Semantic Ambient Media: From Ambient Advertising to Ambient-Assisted Living. *Multimedia Tools App.* 58, 2 (2012), 399–425.

[53] A.S.M.M. Rahman, J. Saboune, and A. El Saddik. 2011. Motion-Path Based in Car Gesture Control of the Multimedia Devices. In *DIVANet '11*. ACM, New York, NY, USA, 69–76. https://doi.org/10.1145/2069000.2069013

[54] M. Raja, V. Ghaderi, and S. Sigg. 2018. WiBot! In-Vehicle Behaviour and Gesture Recognition Using Wireless Network Edge. In *ICDCS '18*. 376–387. https://doi.org/10.1109/ICDCS.2018.00045

[55] B. Reimer, B. Mehler, J. Dobres, H. McAnulty, A. Mehler, D. Munger, and A. Rumpold. 2014. Effects of an "Expert Mode" Voice Command System on Task Performance, Glance Behavior & Driver Physiology. In *AutomotiveUI '14*. ACM.

[56] A. Riener, A. Ferscha, F. Bachmair, P. Hagmüller, A. Lemme, D. Muttenthaler, D. Pühringer, H. Rogner, A. Tappe, and F. Weger. 2013. Standardization of the In-Car Gesture Interaction Space. In *AutomotiveUI '13*. ACM, 14–21.

[57] W. A. Rogers, A. D. Fisk, A. Collins McLaughlin, and R. Pak. 2005. Touch a Screen or Turn a Knob: Choosing the Best Device for the Job. *Human Factors* 47, 2 (2005), 271–288. https://doi.org/10.1518/0018720054679452

[58] F. Roider and T. Gross. 2018. I See Your Point: Integrating Gaze to Enhance Pointing Gesture Accuracy While Driving. In *AutomotiveUI '18*. ACM, New York, NY, USA, 351–358. https://doi.org/10.1145/3239060.3239084

[59] F. Roider and K. Raab. 2018. Implementation and Evaluation of Peripheral Light Feedback for Mid-Air Gesture Interaction in the Car. In *IE '18*. 87–90.

[60] F. Roider, L. Reisig, and T. Gross. 2018. Just Look: The Benefits of Gaze-Activated Voice Input in the Car. In *Adjunct AutomotiveUI '18*. ACM, New York, NY, USA, 210–214. https://doi.org/10.1145/3239092.3265968

[61] F. Roider, S. Rümelin, B. Pfleging, and T. Gross. 2017. The Effects of Situational Demands on Gaze, Speech and Gesture Input in the Vehicle. In *AutomotiveUI '17*.

[62] F. Sachara, T. Kopinski, A. Gepperth, and U. Handmann. 2017. Free-hand gesture recognition with 3D-CNNs for in-car infotainment control in real-time. In *ITS '17*. 959–964. https://doi.org/10.1109/ITSC.2017.8317684

[63] P. Sauras-Perez, J. Taiber, and J. Smith. 2014. Variability analysis of in-car gesture interaction. In *ICCVE '14*. 777–780. https://doi.org/10.1109/ICCVE.2014.7297657

[64] O.A. Schipor, R.-D. Vatavu, and J. Vanderdonckt. 2019. Euphoria: A Scalable, Event-Driven Architecture for Designing Interactions Across Heterogeneous Devices in Smart Environments. *Inf. and Software Technology* 109 (2019), 43–59.

[65] O. A. Schipor and R.-D. Vatavu. 2019. Towards Interactions with Augmented Reality Systems in Hyper-Connected Cars. In *EICS Workshops 2019*. 76–82. http://ceur-ws.org/Vol-2503/paper1_12.pdf

[66] G. Shakeri, J. H. Williamson, and S. Brewster. 2017. Novel Multimodal Feedback Techniques for In-Car Mid-Air Gesture Interaction. In *AutomotiveUI '17*. ACM, New York, NY, USA, 84–93. https://doi.org/10.1145/3122986.3123011

[67] G. Shakeri, J. H. Williamson, and S. Brewster. 2018. May the Force Be with You: Ultrasound Haptic Feedback for Mid-Air Gesture Interaction in Cars. In *AutomotiveUI '18*. ACM, 1–10. https://doi.org/10.1145/3239060.3239081

[68] G. Shakeri, J. H. Williamson, and S. A. Brewster. 2017. Bimodal Feedback for In-Car Mid-Air Gesture Interaction. In *ICMI '17*. ACM, New York, NY, USA, 518–519. https://doi.org/10.1145/3136755.3143033

[69] M. Sheik-Nainar, J. Huber, R. Bose, and N. Matic. 2016. Force-Enabled TouchPad in Cars: Improving Target Selection Using Absolute Input. In *CHI EA '16*. ACM, 2697–2704. https://doi.org/10.1145/2851581.2892390

[70] L. Shen, S. Huo, M. Chen, F. Li, F. Yao, and H. Shen. 2017. Multi-touch gesture recognition algorithm of vehicle electronic devices-based on Bezier curve optimization strategy. In *YAC '17*. 720–723. https://doi.org/10.1109/YAC.2017.7967503

[71] K. A. Smith, C. Csech, D. Murdoch, and G. Shaker. 2018. Gesture Recognition Using mm-Wave Sensor for Human-Car Interface. *IEEE Sensors Letters* 2, 2 (2018), 1–4. https://doi.org/10.1109/LSENS.2018.2810093

[72] J. Sterkenburg, J. Johnson, S. Landry, and M. Jeon. 2016. Development Tool for Rapid Evaluation of Eyes-Free In-Vehicle Gesture Controls. In *AutomotiveUI '16 Adjunct*. 15–19. https://doi.org/10.1145/3004323.3004357

[73] J. Sterkenburg, S. Landry, and M. Jeon. 2017. Eyes-Free In-Vehicle Gesture Controls: Auditory-Only Displays Reduced Visual Distraction and Workload. In *AutomotiveUI '17*. 195–200. https://doi.org/10.1145/3131726.3131747

[74] A. Tamoto and K. Itou. 2019. Voice Authentication by Text Dependent Single Utterance for In-Car Environment. In *SoICT '19*. ACM, New York, NY, USA, 336–341. https://doi.org/10.1145/3368926.3369669

[75] M. P. Tarvekar. 2018. Hand Gesture Recognition System for Touch-Less Car Interface Using Multiclass Support Vector Machine. In *ICICCS '18*. 1929–1932. https://doi.org/10.1109/ICCONS.2018.8663003

[76] S. Tateno, Y. Zhu, and F. Meng. 2019. Hand Gesture Recognition System for In-car Device Control Based on Infrared Array Sensor. In *SICE '19*. 701–706. https://doi.org/10.23919/SICE.2019.8859832

[77] A. Tewari, B. Taetz, F. Grandidier, and D. Stricker. [n.d.]. A Probabilistic Combination of CNN and RNN Estimates for Hand Gesture Based Interaction in Car, year=2017. In *ISMAR '17 Adjunct*. 1–6.

[78] M. T. Tombeng, R. Najoan, and N. Karel. 2018. Smart Car: Digital Controlling System Using Android Smartwatch Voice Recognition. In *CITSM '18*. 1–5. https://doi.org/10.1109/CITSM.2018.8674359

[79] S. Tsurufuji, H. Ohnishi, M. Iida, R. Suzuki, and Y. Sumi. 1991. A Voice Activated Car Audio System. In *CE '91*. 340–341. https://doi.org/10.1109/ICCE.1991.733216

[80] S. Tsurufuji, H. Ohnishi, M. Iida, R. Suzuki, and Y. Sumi. 1991. A voice activated car audio system. *IEEE Transactions on Consumer Electronics* 37, 3 (1991), 592–597. https://doi.org/10.1109/30.85572

[81] J. Vanderdonckt, M. Zen, and R.-D. Vatavu. 2019. AB4Web: An On-Line A/B Tester for Comparing User Interface Design Alternatives. *Proc. ACM Hum.-Comput. Interact.* 3, EICS, Article 18 (June 2019), 28 pages. https://doi.org/10.1145/3331160

[82] R.-D. Vatavu and J. O. Wobbrock. 2015. Formalizing Agreement Analysis for Elicitation Studies: New Measures, Significance Test, and Toolkit. In *CHI '15*. ACM, New York, NY, USA, 1325–1334. https://doi.org/10.1145/2702123.2702223

[83] R.-D. Vatavu and J. O. Wobbrock. 2016. Between-Subjects Elicitation Studies: Formalization and Tool Support. In *CHI '16*. ACM, New York, NY, USA, 3390–3402. https://doi.org/10.1145/2858036.2858228

[84] B. Verma and A. Choudhary. 2018. Framework for dynamic hand gesture recognition using Grassmann manifold for intelligent vehicles. *IET Intelligent Transport Systems* 12, 7 (2018), 721–729. https://doi.org/10.1049/iet-its.2017.0331

[85] F. Weidner and W. Broll. 2019. Interact with Your Car: A User-Elicited Gesture Set to Inform Future in-Car User Interfaces. In *MUM '19*. ACM, New York, NY, USA, Article 11, 12 pages. https://doi.org/10.1145/3365610.3365625

[86] S. Werner. 2014. The Steering Wheel as a Touch Interface: Using Thumb-Based Gesture Interfaces as Control Inputs While Driving. In *AutomotiveUI '14 Adjunct*. ACM, NY, USA, 1–4. https://doi.org/10.1145/2667239.2667299

[87] J. O. Wobbrock, M. R. Morris, and A. D. Wilson. 2009. User-Defined Gestures for Surface Computing. In *CHI '09*. ACM, New York, NY, USA, 1083–1092. https://doi.org/10.1145/1518701.1518866

[88] P.N.Y. Wong, D.P. Brumby, H.V.R Babu, and K. Kobayashi. 2019. Voices in Self-Driving Cars Should Be Assertive to More Quickly Grab a Distracted Driver's Attention. In *AutomotiveUI '19*. 165–176. https://doi.org/10.1145/3342197.3344535

[89] J. Wu and M. M. Trivedi. 2006. Visual Modules for Head Gesture Analysis in Intelligent Vehicle Systems. In *IVS '06*. https://doi.org/10.1109/IVS.2006.1689598

[90] Q. Ye, L. Yang, and G. Xue. 2018. Hand-free Gesture Recognition for Vehicle Infotainment System Control. In *VNC '18*. 1–2.

[91] P. Zheng, M. McDonald, and C. Pickering. 2008. Effects of Intuitive Voice Interfaces on Driving and In-vehicle Task Performance. In *ITS '08*. 610–615. https://doi.org/10.1109/ITSC.2008.4732605

[92] M. Zobl, M. Geiger, B. Schuller, M. Lang, and G. Rigoll. 2003. A real-time system for hand gesture controlled operation of in-car devices. In *ME '03*, Vol. 3. III–541. https://doi.org/10.1109/ICME.2003.1221368