Exploring Application Opportunities for Smart Vehicles in the Continuous Interaction Space Inside and Outside the Vehicle

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Abstract. We describe applications that implement interactions between the driver and their smart vehicle in a *continuous interaction space* characterized by the physical distance to the vehicle and by the smart devices that implement those interactions. Specifically, we demonstrate the principles of smart vehicle proxemics with smart rings, smartwatches, smartphones, and other devices employed to interact with the in-vehicle infotainment system while the driver traverses five distinctly identifiable zones, from inside the vehicle to the personal, proximal, distant, and covert zone outside the vehicle. We present engineering details of our applications that capitalize on standardized web technology (HTML, CSS, JavaScript), communication protocols (WebSocket), and data formats (JSON) and, thus, enable straightforward extension to accommodate other smart devices for new interactions with smart vehicles. We also point to future opportunities for designing interactions from a distance and function of the distance between the driver and their vehicle.

Keywords: Smart vehicles · Connected vehicles · Proxemic interactions · Smart ring · Smartwatch · Wearables · Engineering interactive systems

1 Introduction

Smart vehicles embed a variety of sensing and processing systems to enable interactions with the driver and the passengers, but also with a variety of entities around the vehicle, such as other vehicles, buildings, road infrastructure, and pedestrians [22]. Prior work on interacting with smart vehicles has focused almost entirely on in-vehicle input [5,8] and proposed a variety of gesture, voice, eye gaze, and multimedia input techniques for applications inside the vehicle.

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Recent work [6] has brought a new perspective in this landscape by formalizing outside-the-vehicle interactions, where drivers interact with vehicles from a distance.

In this paper, we explore interactions with the vehicle performed outside the vehicle from the perspective of a *continuous interaction space*. Within this continuous space, drivers interact fluently with their vehicle as they approach and enter the vehicle or as they exit the vehicle and walk away, while the in-vehicle system and the drivers' mobile and wearable devices are aware of and effectively exploit the physical distance between the driver and the vehicle. To demonstrate the opportunities of this continuum, we present several interactions with a smart vehicle, e.g., *implicit interaction*, when data from the vehicle is stored on an NFC ring worn by the driver, and *explicit interaction* when the driver remotely connects using their smartphone to the in-vehicle infotainment system to resume music playing from the vehicle's playlist. We present the engineering details of four web-based applications designed for a smart ring, smartwatch, smartphone, and a desktop computer. By interpreting interactions with the vehicle as occurring in a continuous space defined by both the physical distance to the vehicle and the smart devices to implement those interactions, new opportunities open for designing rich user experiences for drivers when outside their vehicles.

2 Related Work

We synthesize prior work addressing interactions inside the vehicle, and we connect to the scientific literature on proxemic interactions and, especially, its recent application to smart vehicles [6] enabling outside-the-vehicle interactions.

2.1 Interactions with Smart Vehicles

In-vehicle interactions have been studied to a large extent, and many techniques have been proposed to increase driving safety and journey comfort. These include techniques based on gestures [9], voice input [2], eye gaze [23], and multimodal interactions [8]; see Bilius and Vatavu's [4] overview of input modalities for media consumption inside the vehicle. Each modality comes with specific benefits for drivers. For instance, gesture-based interfaces informed by elicitation studies [9] should be highly intuitive to drivers as they capitalize on gestures reflective of users' behaviors and mental models for interacting inside the vehicle; voice input enables drivers to keep their hands on the steering wheel and eyes on the road [2]; finger-augmentation devices, such as smart rings, open the possibility to interact with the vehicle by transferring controls from the steering wheel to the fingers [10]; and multimodal input techniques enable switching between various input modalities according to the specific context on the road and driver's preferences [8]. While these interactions have been proposed for the space inside the vehicle, a recent work [6] has shown that interactions outside the vehicle are equally relevant for drivers, and formalized such interactions with the proxemics theory [12]. We discuss this direction next from the perspective of a timeline of milestones in proxemic interactions and autonomous and smart vehicles.

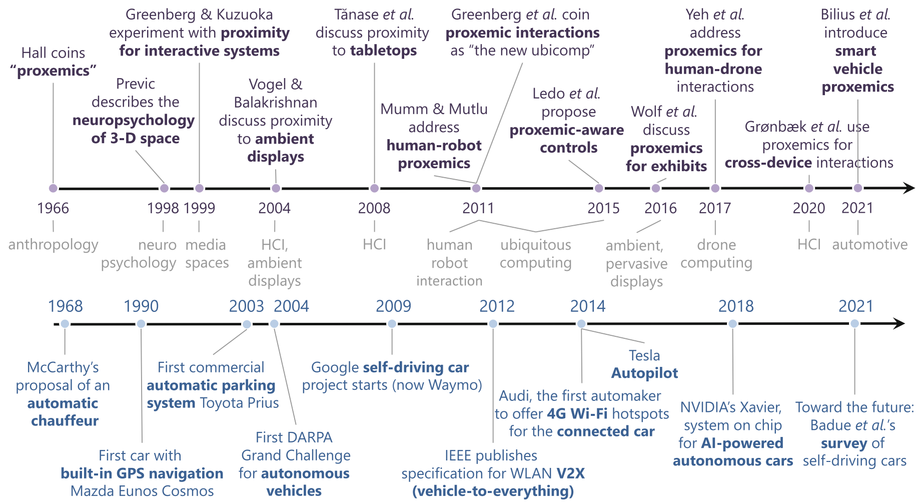

Fig. 1. A timeline of proxemic interactions (top) and autonomous vehicles (bottom) representing the recent context in which we position our work and contributions.

2.2 Proxemic Interactions and Smart Vehicles

The concept, principles, and tools of proxemic interaction [3,12,18] enable the design and engineering of interactive computing systems that employ the relative distance and orientation of users and other objects from the physical environment to adapt and react accordingly. Figure 1, top shows a timeline of investigations on proxemic interactions and applications to various areas—informed by Hall's [14] seminal proxemics theory, Previc's [21] neuropsychology of 3D space, and Greenberg and Kuzuoka's [11] original experiments with digital and physical surrogates as mediators for human interaction. Notable applications have targeted ambient displays [28], tabletops [27], robots [20], drones [30], smart homes [17], museum exhibits [29], and cross-device input [13]. The most recent application of proxemic interaction has addressed smart vehicles to enable interactions outside the vehicle [6]. Figure 1, bottom complements this timeline with milestones of research on autonomous and smart vehicles, from McCarthy's [19] vision of an automatic chauffeur at the onsets of AI to the Vehicle-to-Everything (V2X) specification [22], 4G Wi-Fi for vehicles [16], and self-driving cars [7].

At the intersection of proxemic interactions and smart vehicles, Bilius *et al.* [6] introduced the smart vehicle proxemics framework with a conceptual space for formalizing interactions outside the vehicle according to (i) the physical distance between the driver and the vehicle, (ii) the paradigm to interact with the vehicle, and (iii) the driver's goal. The framework specifies five proximity zones with respect to the vehicle: *inside* the vehicle, *personal* (the driver is close to the vehicle that they can easily reach and touch it), *proximal* (the driver is close to the vehicle, but far enough so that they cannot touch it), *distant* (the driver is farther away, but the vehicle is still in their visual field), and *covert* (the driver cannot see their vehicle). The authors proposed the rough guidelines of 1 m, 10 m, and 100 m to delineate these zones in relation to operating ranges of Class 1, 2, and 3 Bluetooth communications, a technology commonly used in smartphones, smartwatches, smart bracelets, etc. However, the framework has remained theoretical and applications yet to be demonstrated. In this work, we demonstrate interactions for mobile and wearable devices in a continuous space that starts inside the vehicle and ends in the covert zone.

3 Applications in the Continuous Interaction Space Inside and Outside the Vehicle

We illustrate the smart vehicle proxemics framework [6] with concrete interactive applications for mobile and wearable devices. We demonstrate interactions that span across the continuous space that starts with the driver inside the vehicle and follows the driver as it departs from the vehicle. In this space, the goals of the driver change as a function of the distance to their car, and those goals are accomplished with different devices, e.g., a smart ring when near the vehicle or a desktop computer when the user is in the comfort of their home. To this end, we consider the following support story to introduce our applications:

> *"Mary and Emma are long time friends. One day, they plan a trip to a nearby city with many attractions. It takes them a while to get there by car, so the two decide to listen to music to make the time pass faster—the new album of their favorite band that Mary has already uploaded to the infotainment system of her car. After two hours, they arrive at their destination. Mary parks the car and, while locking the vehicle, she touches the door handle just briefly, which is enough for data from the vehicle to be transferred to the smart ring from her finger. While they both walk away from the car, Mary receives a notification on her smartwatch confirming that the car is locked and safe, which she acknowledges with a quick turn of the hand. After a few more steps, the smartwatch vibrates slower and slower to signal that its Bluetooth connection with the vehicle was lost as they continue to walk farther away. Later during the day, Mary uses an app on her smartphone to connect to the infotainment system of her car via a mobile Internet connection, and they resume listening to the song last playing in the car. Mary and Emma spend a wonderful day enjoying all the attractions of the city they are visiting. Returning to the parking lot, Mary has troubles remembering where she parked, so she touches her ring to the smartphone, which displays the map with the GPS location of the car stored on the ring when Mary locked the vehicle. A mere touch between the ring and the smartphone is enough for the smartphone to automatically launch the smart vehicle app from the many applications installed on Mary's phone. In the evening, they arrive back home. Emma asks Marry for a guest passcode to remotely connect to the infotainment system of Mary's car to download the music playlist they have enjoyed during the journey."*

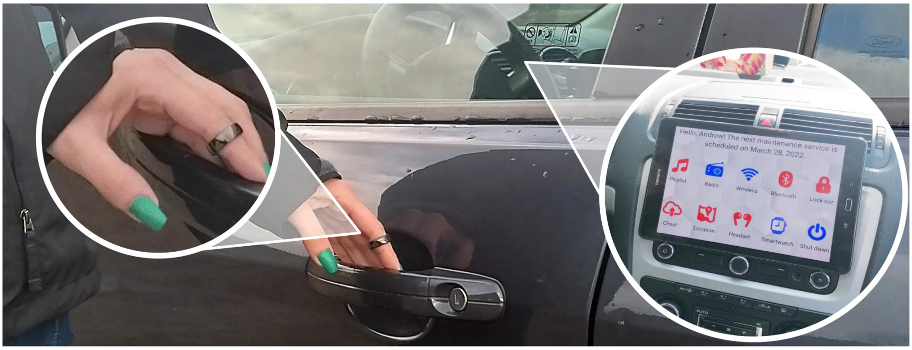

Fig. 2. Interaction with the smart vehicle in the personal zone: an NFC ring receives data from the vehicle when in contact with an active NFC component from the vehicle.

When in the *personal zone*, the driver is very close to their vehicle (at about 1 m) and, thus, interactions in this zone can be implemented with direct touch input. Also, this zone is usually traversed quickly while the driver enters or exists the vehicle, but even this brief period of time is enough for *implicit interactions*. For instance, when in the personal zone, data can be transferred between the vehicle and the driver's personal devices, such as the GPS location of the vehicle can be stored on the driver's ring when in contact with an active component from the vehicle; see Fig. 2 for an illustration where the OMNI NFC Ring[1] is worn by the user and a reader could be embedded in the door handle. We implemented an application for the OMNI Ring (NFC Type B, Infineon SLE78 security controller, Java Card OS, dual 16-bit core CPU, 80 kB user memory, and AES/TDES/RSA 2k/ECC 521 cryptography standards) in the form of an Android app that writes and reads the following data to/from the ring: vehicle id, GPS location, parking ticket info, and the IP address of the vehicle. The application runs on an Android device, which can be the infotainment system of the car, as illustrated in Fig. 2, to which an NFC reader/writer is connected. In our implementation, we employed a Samsung Tab A T555 device.[2]

The proximal zone is followed by the *personal zone* at an approximate distance of 10 m from the vehicle. In this zone, the driver approaches the vehicle or departs from it but, unlike in the personal zone, direct interactions by touching the vehicle are no longer possible. In this zone, Class 2 Bluetooth devices still operate[3] and can exchange information with the vehicle. In our example, Mary receives a notification on her smartwatch a few seconds after she has locked the car, comforting her that the car is indeed safely locked; see Fig. 3 for an illustration of this scenario. The smartwatch is preferred to deliver such notifica-

[1] https://store.nfcring.com/products/omni?variant=30878229987373.
[2] https://www.samsung.com/au/support/model/SM-T555NZWAXSA.
[3] Typical range of operation of 10m; see a Bluetooth rang estimator here: https://www.bluetooth.com/learn-about-bluetooth/key-attributes/range.

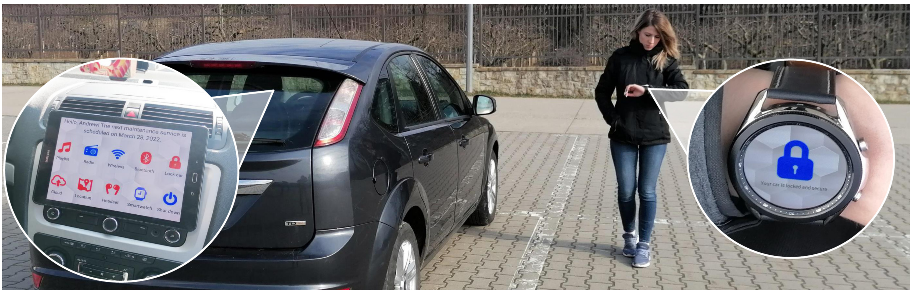

Fig. 3. Interaction with the vehicle in the proximal zone: the smartwatch delivers a notification from the vehicle, letting the driver know that the vehicle is locked and safe.

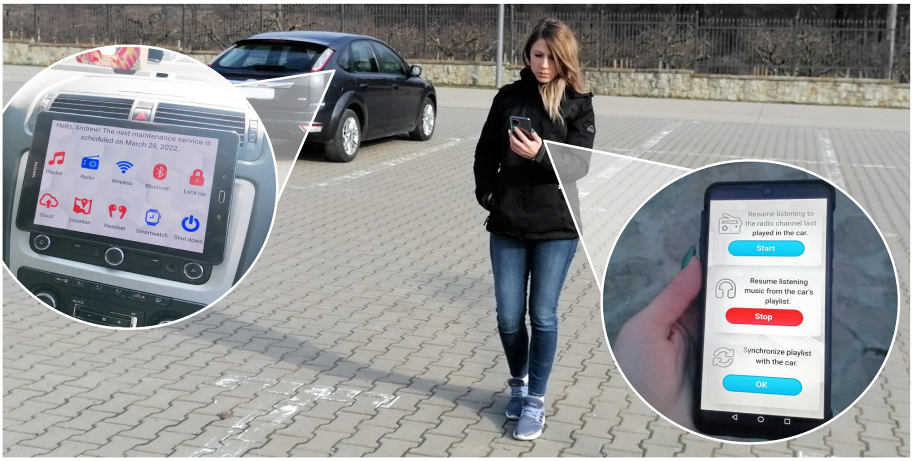

Fig. 4. Interaction with the vehicle in the distant zone: a smartphone app enables transfer of data from the vehicle as the driver approaches or walks away from their car.

tions compared to a smartphone since it is readily available on the user's wrist and the interaction for consuming the notification is brief. We implemented a Tizen web application for the Samsung Watch3[4] (Dual-Core 1.15 GHz CPU, 1 GB RAM) using HTML, CSS, and JavaScript that communicates full-duplex via the WebSocket protocol with the tablet device from the vehicle representing the in-vehicle infotainment system. Notifications are sent from the infotainment system to the watch and acknowledged by the user with a simple arm movement.

The *distant zone* continues after the proximal zone, up to a distance of about 100 m around the vehicle [6]. Just like in the proximal zone, the driver can visually locate their vehicle. However, the larger distance creates the need for

[4] https://www.samsung.com/us/mobile/wearables/smartwatches/galaxy-watch3-45mm-mystic-silver-bluetooth-sm-r840nzsaxar/.

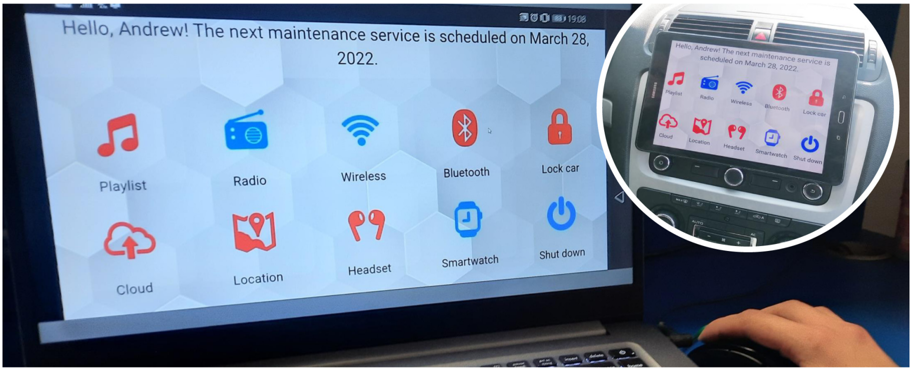

Fig. 5. Interaction with the smart vehicle in the covert zone: the user connects to the in-vehicle infotainment system with a remote desktop application.

new communication channels and devices. Examples include Class 1 Bluetooth devices that operate at a typical range of 100 m and mobile Internet connections provided by a wireless carrier. In our story, Mary connects to her vehicle to synchronize data and resume playing music from the car on her smartphone; see Fig. 4 for an illustration. In our implementation, a node.js web server handles communications with client applications requesting data via the WebSocket protocol. An Android app, running on the smartphone, acts as the client enabling Mary to resume listening to the music from the vehicle and to synchronize the playlist from the smartphone with that from the vehicle.

The *covert zone* is primarily characterized by the fact that the vehicle is no longer in view [6]. There is no fixed threshold in meters to demarcate the covert and distant zones, but typical applications in this zone assume that the user has access to desktop computers, such as in an office or at home. In our scenario, Emma wishes to access the playlist from Mary's car and asks for a guest passcode to connect to the in-vehicle infotainment system. Figure 5 illustrates this use case scenario, where we employed the AnyDesk[5] application to connect to the tablet device located in the vehicle from a desktop computer. In our implementation, the data stored on the ring also contains the IP address of the vehicle and Mary can simply touch Emma's smartphone to transfer this information.

4 Discussion

We presented interactions with a smart vehicle while the driver is outside the vehicle and at various distances from the vehicle in order to demonstrate the opportunities outlined by the smart vehicle proxemics framework [6]. These interactions employed convenient devices to minimize the effort and maximize the effectiveness of communicating with the vehicle when in various proximity zones around the vehicle. Although intended to be simple, our applications

[5] The fast remote desktop application - AnyDesk, https://anydesk.com/en.

demonstrate the opportunities for designing interactions outside the vehicle in a continuous space characterized by the combination between physical distance and a variety of devices to mediate those interactions. Moreover, since all the communications with the vehicle are handled via standardized web protocols and data formats, it is easy to extend our applications towards new devices and platforms, e.g., smartglasses [1], augmented reality [25], specialized software architecture [26], etc., and achieve new functionalities. For instance, other scenarios in the *personal zone* could use NFC tags embedded in jewellery [24], tattoos [15], or key rings,[6] and the information stored by those tags could address a variety of other applications, e.g., information about the technical state and inspection of the vehicle, consumption statistics, travel history, vehicle safety and location, etc.; see [6] for a study examining drivers' preferences for information to obtain from their vehicle while close to the vehicle. Other scenarios in the *proximal zone* could show the expiry time of the parking ticket as a reminder to the driver walking away from the vehicle or the inside temperature of the car when the driver is in the *distant zone* and approaching the vehicle, so that the driver could already make the appropriate setting for the air conditioning and heating system before reaching their car. Our web-based implementations can handle flexible associations between devices and the in-vehicle system and, thus, support the fluency of interacting in the continuous space inside and outside the vehicle.

5 Conclusion

We presented application opportunities for interacting with smart vehicles enabled by mobile and wearable devices employed fluently by the user according to the physical distance to the vehicle and their goals. To this end, we envisioned a continuous interaction space in which drivers move freely and interact with the vehicle as they depart or approach the vehicle. Our practical applications complement the theoretical discussion of the smart vehicle proxemics framework and demonstrate its practical usefulness with an illustrative scenario involving interactions with the smart vehicle when in various zones around the vehicle.

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[6] https://www.hidglobal.com/sites/default/files/resource_files/hid-nfc-tags-and-solutions-wp-en.pdf.

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