WoZ Way: Enabling Real-Time Remote Interaction Prototyping & Observation in On-Road Vehicles

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ABSTRACT
Interaction designers often have difficulty understanding people's real-world experiences with ubiquitous systems. The automobile is a great example of these challenges, where on-road testing is time-consuming and provides little ability for rapid prototyping of interface behavior. We introduce WoZ Way, a system to connect designers to remote drivers. We use live video, audio, car data, and Wizard of Oz speech and interfaces to enable remote observation and interaction prototyping on the road. Our implementation integrates environmental, system level, and social information to make the invisible visible. We tested across three example deployments highlighting usage in interaction prototyping and observational studies. Our findings illustrate how designers explored the situated experiences of people on the road, and how they experimented with different improvisational Wizard of Oz interactions. WoZ Way is both a design research and a design prototyping tool, which can support the work of interaction designers through naturalistic observations, contextual inquiry, and responsive interaction prototyping.

ACM Classification Keywords
H.5.2. User Interfaces: User-centered design;

Author Keywords
Interaction Design; Design Methods; Wizard of Oz; Prototyping; Ethnography

INTRODUCTION
The automobile is a space where many people spend much of every day, yet in many ways, it is understudied. There is no shortage of products for the car; with infotainment displays, navigation systems, and semi-automated driving features, the car is a multifunctional living space, an interconnected workplace and a personal communication center [27]. However, it can be a challenging site to research, and an even more challenging site to design for. On one hand, the car's cabin is relatively controlled, readily instrumented, and provides a

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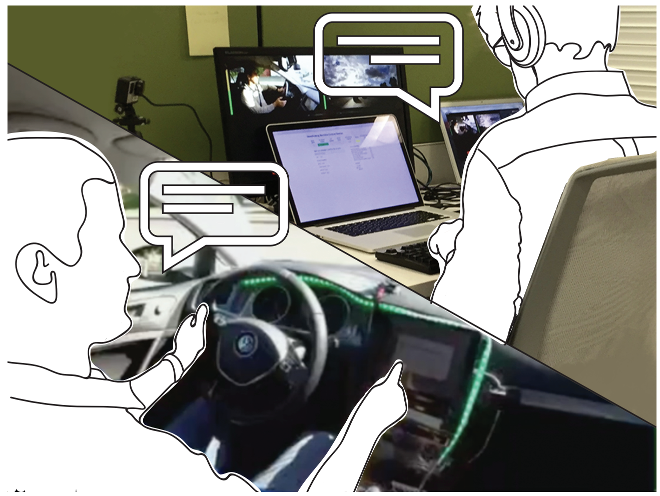

Figure 1. WoZ Way, a real-time interaction prototyping and observation system connecting designers to drivers on the road.

unique opportunity for understanding people. On the other, cars are on the move and are constantly changing contexts. Sometimes the person driving the car is interacting with others in the car. Sometimes the driver is interacting with the information presented on the dashboard, on the center console, on brought-in mobile devices, or on the entertainment system. It is nigh impossible to replicate the richness and spontaneity of everyday driving in a laboratory simulator [35]. Even in a real car driving on real roads, designers and researchers often face challenges including geographical logistics, the observer's influence on drivers and passengers, social interaction challenges, difficulty studying groups, and even car sickness [32].

In this paper, we present WoZ Way, a system to enable remote observation and interaction prototyping in a car. WoZ Way enables designers to remotely observe and test new driving experiences and interfaces. It provides designers with the ability to observe environmental, system and social information from the car, and to interact with drivers in real-time. Our system is intended to help designers and researchers to better respond to the situated contexts of the user without having to be physically present in the car. We outline the design and implementation of the system and present three test deployments highlighting the use of WoZ Way for interaction prototyping and user experience research. We discuss how the system extends the research tools for interaction designers targeting the automotive context and addresses the shortcomings of existing in-vehicle field-based design methods. We feel that by allowing the designer to be in the car without "being there," WoZ Way can enable many new opportunities for CSCW research in the car.

Safety

These new opportunities for conducting on-the-road research also come with the inherent risks of testing new automotive interactions. One of the reasons we have designed this system is to prototype interactions to make sure they are safe. One of the corollaries of this is that some of the interactions we are prototyping may be dangerous. From an ethical perspective, it is preferable to discover safety issues during design, development, and testing rather than in commercial production vehicles. On-road testing of prototype cars and interfaces is common in the automotive industry. As in-car interactions become increasingly computer enabled, automotive HCI research will become even more important. Our system enables a new form of conducting this type of work so that new interactions can be designed, tested and understood before moving to mass production.

We also consider saftey from a human-subjects perspective and recommend that researchers exploring automotive interaction design consider the saftey of their participants. We fully disclose the risks of driving and on-road testing to participants in our studies. All experiments take place with real-time researcher supervision. To mitigate risk while testing, we anticipate possible issues in advance, take as many saftey precautions as possible, and have prepared researchers to respond to issues should they arise. By acknowledging risks and taking precautions, we feel that HCI researchers can responsibly explore new on-road interactions.

RELATED WORK

Design Research Methods in Cars

Designers have explored the automotive environment using a variety of design research tools. Designers often interview people using speculative participatory design methods [38] or have them fill out diaries after a drive to understand the in-car experience, for example, with music and sound in the car [3]. These post-facto methods can provide rich depictions of user experience, but limit designers to moments that the users noticed and remembered. Incorporating in-vehicle video recording of naturalistic driving allows for post-drive video analysis, but researchers often lose the ability to inquire what is being thought about or observed in-the-moment. For this reason, Perterer et al. argue that truly understanding drivers and passengers can only be done by being in the car [37].

In-situ methods such as contextual inquiry, ethnographic study, and cultural probes can be adapted to the constraints of the car; for instance, in-car observation and contextual inquiry have been used to understand the use of GPS navigation systems [30] and to test the design of new collaborative navigation apps [15, 22]. During these studies, the experimenter can observe the real-time experience of drivers and interact by asking questions. However, Meschtscherjakov et al. note that the presence of the researcher in the car presents its own problems [32]. For instance, coordinating a researcher to ride-along can be difficult and can limit drives to pre-planned routes, and cut down on the spontaneity of naturalistic driving. The presence of the researcher can also bias the behavior of the participants and potentially influence the driver's actions or make the driver feel uncomfortable if they do not know the researcher. It can also be challenging for the researcher to observe the situation at a high-level, take detailed notes about specific aspects of the drive, and control the behavior of interactive prototypes. Researchers can also become motion sick while attempting to write notes or control screen interfaces in the car. Finally, any interaction within the car can pose a safety risk by distracting the driver. We have developed WoZ Way in order to address the associated challenges with in-vehicle observation and interaction prototyping while still providing designers a rich view of the on-road experience. Our system employs remote communication technology with a Wizard of Oz methodology to allows a researcher to "be there" without actually needing to be there.

Wizard of Oz Interaction Prototyping in Driving Studies

Originally developed by J.F. Kelley to prototype an interactive, speech based computer calendar service in 1983 [26], the Wizard of Oz (WoZ) methodology has long been used to stand in for computational recognition, planning, and interaction systems that do not yet exist. From a design perspective, WoZ enables a fluid and improvisational means to test new design ideas and to understand people using the technology in specific contexts [12]. With well designed WoZ systems, non-technical designers can engage in rapid interactive prototyping of the behavior of new interfaces [28] and explore new interaction possibilities between people and technology [34].

WoZ methods have long been used in automotive interaction design to simulate and explore systems requiring considerable hardware for sensing or processing. Often, these experiments involve driver interfaces in on-the-road test vehicles which were surreptitiously controlled by a back seat experimenter with a numeric keypad [21, 20, 19] or tablet PC [23]. WoZ techniques are also frequently employed to develop speech interfaces for cars [18, 29] and collect data for bootstraping natural language algorithms [11, 42]. WoZ speech systems have also been used to explore user experience. Sirkin et al. [40] used WoZ speech in a driving simulator to promote ad hoc conversation with drivers. This setup enabled researchers to inquire what people were thinking and feeling while minimizing the distorting effects that can occur when people are being interviewed in person, a common issue for usability researchers [41].

Recently, WoZ has been used to simulate wholly autonomous vehicles. Schmidt et al. [39] modified a vehicle to have a hidden compartment with driving controls for the Wizard. This allowed the Wizard to fully simulate and prototype the behavior of advanced driving features such as automatic lane keeping and infotainment interfaces. Furthering this work, the Real-Road Autonomous Driving Simulator (RRADS) system utilized both a hidden Driving Wizard to simulate autonomous driving and a known Interaction Wizard in the back seat to control various car interfaces [1]. While these studies have shown the benefits of the WoZ methodology for on-road interaction studies, they can require significant modifications to keep the Wizard hidden in the car and to preserve ecological validity. To avoid these challenges, we have taken inspiration from the ubiquitous computing community to create a system that allows remote WoZ interaction and observation. In doing so, we allow designers to experiment remotely with driving experiences in an ecologically valid manner [5].

Remote Observation and Interaction Prototyping

Much of the prior work in remote observation techniques for designers to understand users comes from the mobile phone space. Early systems focused on extending the experience sampling method [10] as a technique to evaluate and improve ubicomp applications [8]. Froehlich's MyExperience, for example, enables designers to survey users after specific interactions with their device [16]. One example had users rate the call quality after a mobile phone call on the phone itself. Carter et al.'s Momento [4] was developed to help designers better understand the in-world context in which people were using mobile computing applications. Designers receive notifications around specific trigger events notifying of a participant's mobile application use, in real-time. They can subsequently interact with the user over multimedia messaging by sending questions and requesting photos or videos of the user's environment.

While the discrete messaging model of Momento worked well for the incidental use patterns typical of mobile applications, higher bandwidth models for observation and interaction are required to enable continuous and sustained experiences. McIntyre et al.'s DART allows designers to prototype augmented reality experiences in real-time, responding to interaction data transmitted over a network [31]. In one implementation, the designers prototyped a "voices of the dead" storytelling experience of the Oakland Cemetery [13] by following participants from a short distance, logging their GPS coordinates, and triggering audio on their AR interface.

In discussing the future of remote interaction design tools, Crabtree et al. point out that many aspects of interaction in ubiquitous environments are invisible and fragmented, and that "there is a strong need to enhance observation in these environments, making the invisible visible and reconciling the fragments to permit coherent description." [9] They champion the combined use of video and system data in remote ethnography to enable sensemaking of increasingly computational user experiences. Most recently, Chen and Zhang created a system using Google Glass and video conferencing to remotely paper prototype mobile applications [7]. This system allowed a designer to quickly test low-fidelity prototypes in the wild, helping them discover issues they could have never found in the lab. The WoZ Way system blends the video-based WoZ capabilities of this remote paper prototyping with the data and interaction features of Momento and DART for use in the car.

The automotive setting is a strong example of an environment where the challenges addressed by this previous work in in-situ interaction prototyping are present. Our system goes "beyond being there" [24] to provide the designer with a holistic view of the visible and invisible aspects of the driving experience.

Designers of in-car experiences need to respond in real-time to events that are occurring in the vehicle, around the vehicle, and throughout the drive. An interaction prototyping system that addresses this context needs to integrate information about the driver, from the car, and from the road in order to be complete. The system needs to be networked to span the distance covered by a drive. We extend previous systems, foreshadowed by Carter et al. [4], by providing networked, high-quality, real-time video and automotive data with the ability for designers to directly interact with a driver through speech and in-car interfaces. The architecture of our system allows designers to observe and interact with drivers in their remote contexts, providing a platform for understanding and creating real-world driving experiences. It is both a design research and a design prototyping tool.

THE WOZ WAY SYSTEM

Using WoZ Way, researchers can observe and interact with drivers during their everyday commutes, reducing the logistical struggles of route planning, enabling on-road observation, and allowing real-time prototyping of in-car interface behavior.

Function

WoZ Way allows designers to watch the real-time driving experience via high fidelity video and audio, and also simultaneously receive meta-data about the drive, such as the vehicle telematics data and/or real-time map or traffic information. The designer can also interact or intervene, asking questions by using a text-to-speech messaging system, or remotely triggering custom in-car screen and electromechanical interfaces. Together, this observation and interaction allow the designer to explore and experiment with the driver's experience.

Key Features

The key features of the WoZ Way system include:

- high bandwidth, low latency, self-resurrecting remote connection capabilities
- real-time synchronization of multiple data streams from the car to the designer
- "interaction through a machine" capabilities using multi-language text-to-speech and remote control of electromechanical interfaces to prototype their in-car behavior
- multi-channel data capture to enable post-facto analysis of interactions

Observation

By having a remote connection to the car, a designer can understand experience without physically riding along. This allows for exploration in real-world contexts and shows the designer a much richer picture of someone's experience in the car. Live video and car data streams provide the remote designer more information than what is available to people sitting in the car. With these data streams, designers can take a holistic view of the visible and invisible actions in the car.

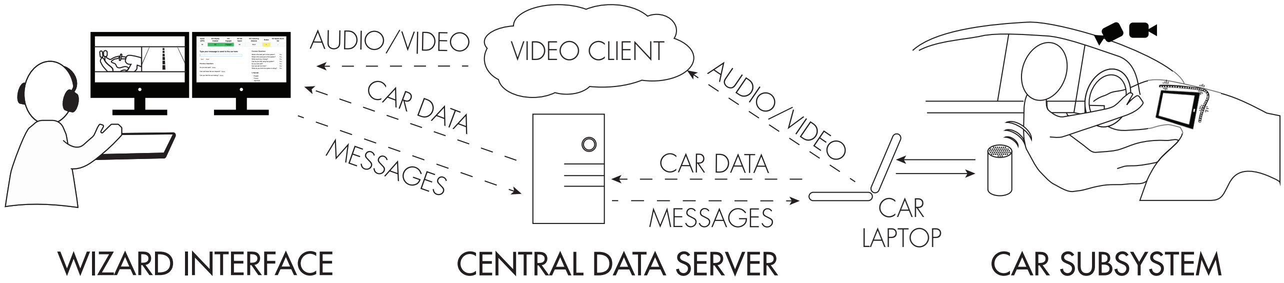

Figure 2. System architecture for on the road, real-time, remote observation and interaction prototyping.

They can observe facial expressions, system usage, and on-road events within a single interface. This helps to bring the data-driven methodologies used for understanding people on the web into the physical world.

The system also allows researchers to be a part of longer one-way drives that would otherwise be inconvenient for the researcher to join, such as a long commute. The mobile nature of the system also allows observation during multiple drives over many days, allowing more longitudinal studies of drivers. Finally, it increases the ability to observe and design services that address passengers, such as children being dropped off or picked up from school or group carpooling.

Data Streaming and Capture

WoZ Way has also been designed to provide the designer more contextual information than potentially possible if the designer were merely riding along in the car, such as a live stream of car data and multiple camera views. This not only gives the designer a richer picture of the driving experience but also helps alleviate the workload to record and respond to low-level details and overall experience. Automatic collection of video, audio, and automotive data also allows designers more freedom to interact with a driver and can be used for more detailed post-drive analysis. Researchers will also avoid motion sickness as they are not writing notes or controlling a computer interface inside of the car. This can allow for safer testing as the designer can focus on their interaction with the driver rather than on the mechanics of the study.

Interaction Prototyping

Interaction between the designer and the participant is enabled through in-car speech, screen, and electromechanical interfaces. Designers can prototype the interactive behaviors of in-car interfaces by interacting through a machine. This allows designers to use connected technology as a design tool to understand people. Additionally, by being the voice and behavior of the machine, the designer simulates the mind of the machine, helping to draw out a sense of the appropriate "goals, plans, expectations, and desires" for future technologies [36]. In some ways, WoZ Way allows the designer to hide, even when interacting with people in the car, by allowing him or her to act as the car. This can help to avoid the unintended biasing pointed out by Meschtscherjakov et al. [32].

Safety

Safety is a key system design consideration for WoZ Way, as it is meant to be used on-the-road with actual drivers. One advantage of the WoZ Way system is that the Wizard can observe both the driver and driving context in real-time. Having the remote observers see what the driver sees on the road helps to mitigate distraction [17]. This allows the Wizard to be judicious in choosing when to interact with the driver, or when to control in-car interfaces responding to the driver or environment. It is important to note that having a view of the road is critical. A video chat of the driver or voice only is can lead to similar problems as cell phone distraction [6]. The system also allows the Wizard or a supervising researcher to easily turn off any interactive prototype during an on-road test. This ability for the Wizard to fully control or disable interactions with the driver is an important capability that is not present in current-day in-vehicle interfaces. In fact, the information about when the Wizard chooses to interact and when the Wizard chooses to wait could be an important input into how future in-vehicle systems interact with drivers.

While it is possible to prototype the behavior of many systems in the car, special care must be given to what interactions will be explored. For example, it is fairly easy to connect to and control vehicle subsystems such as information displays, steering, braking, and acceleration via the CAN interface [33]. In some cases, these may present interesting opportunities for prototyping the car's behavior and may be warranted for some studies. For example, Jung et al. installed and tested custom battery indicators to explore their impact on driver range anxiety in electric vehicles [25]. Researchers have also designed hidden driver compartments allowing an experimenter to prototype features such as lane keeping [39]. While WoZ Way could allow for the remote control of these systems, for safety reasons, we have focused our interaction prototyping on speech interfaces and brought in electromechanical interfaces that do not interfere with the driver's ability to control the car.

Architecture

The system architecture for WoZ Way has three major components as seen from left to right in Figure 2:

1. A Wizard interface with live video, audio, and data displays from the remote vehicle and controls to send text-to-speech messages to the driver or control the behavior of in-car prototypes

2. A mediating data server to manage communication between the remote vehicle and the Wizard interface; the data server also collects time-stamped data logs

3. A computer in the car to collect and share video, audio, and automotive data over the internet with the Wizard interface and to control spoken text-to-speech messages, screen interfaces, and electromechanical components
4. Auxiliary interfaces including screens, sensors and actuators used in each specific study

The components of this architecture allow for data to flow between the remote car and Wizard. Video and audio are streamed from the car using a video chat client. Car data and interface control messages are streamed through a separate, centralized data server. The Wizard interface shows the data streams from these two sources and allows for creating custom device controllers.

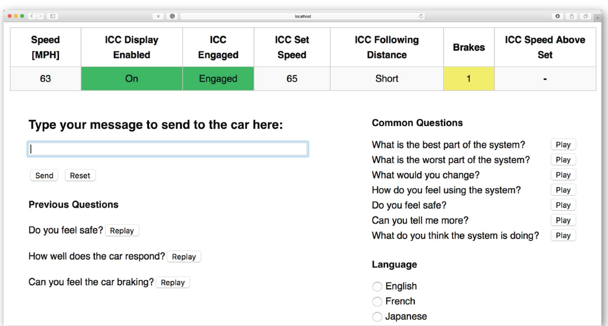

Figure 3. Screenshot of an example Wizard data and control interface.

IMPLEMENTATION

To encourage adoption of WoZ Way as a research platform for in-vehicle experiences, we implemented the majority of the WoZ Way architecture using off-the-shelf hardware and software. Custom software for the in-car data and interaction systems and the Wizard control interface is written using widely available open-source tools and is made available on GitHub for others to modify and reuse. [1]

Wizard Interface

The Wizard interface, which is based on HTML and JavaScript, can be adapted for different applications and deployments. In general, we have found it useful to have the Wizard interface divided into three main regions: The display area, which features the live video, audio, and car data feeds; the Wizard input area, which allows the Wizard to input text and track the history of queries; and the control area, which features buttons for settings, common text-to-speech messages, and custom controls for auxiliary interfaces.

We found it best, when possible, to dedicate a separate HD monitor for the display area, giving the Wizard a large view into and around the car, and leaving more room for the interaction controls. Figure 3 shows a detailed view of the interface that was used in one of our test deployments focused on understanding the driver experience of automatic cruise control systems. Live data from on this interface includes:

- *Vehicle speed [mph]*
- *ICC Display Engaged* - shows if the ICC system is ready and the display on the console is visible to the driver
- *ICC Engaged*- shows if the ICC has control of the vehicle speed, braking, and lane keeping
- *ICC Set Speed* - speed setting for cruise control in [mph]
- *ICC Following Distance* - setting for how much space to leave ahead of car [long, medium, short]
- *Brakes* - indicates if brakes are engaged [1] or off [0]. If brakes engage and *ICC Engaged* stays ON, the car is automatically braking. If brakes engage and ICC Engaged turns OFF, driver is braking manually.
- *ICC Speed Above Set* - indicates if car is traveling at or below set speed [false] or faster than set speed [true]. If [true], driver may have accelerated manually.

Vehicle speed is updated at a rate of 1 Hz. To minimize network bandwidth, transmission of all other data measures are triggered by change events. Color and text are used to encode data values and allowed the Wizard to quickly see changes in the car's state. It should be noted that this information is not available on all cars or is required for all studies. Thus, each interface should be designed with the study goals in mind.

In the input region of the interface, we provide a text input field where the Wizard can send messages to be spoken or displayed in the car. Messages are sent on an "enter" key press or using the "send" button. Sent questions are logged sequentially below the text input field. Each sent message has a "replay" button to quickly repeat the message.

The control region of the interface features a set of common questions or interface controls. A set of pre-programmed messages enables Wizards to respond quickly to common and anticipated events. We also use this region to enable settings, such as the language used by the text-to-speech system, as well as controls for in-vehicle interface prototypes. For example, in a prototype exploring ambient car lighting we included an RGB color picker that allowed the wizard to quickly try how new colors were received.

Using the Wizard interface, designers can observe the data stream and live video from the car. While observing, they can actively query the driver using the text-to-speech messaging system or interface messaging system. With added controls, the Wizard can prototype screen or electromechanical interface interactions.

Mediating Data Server

A centralized data server is used to manage communication between the Wizard and the car. All car data and input messages are routed through this server so the Wizard interface and car only need to communicate with the data server. This allows the Wizard station to be used in different network locations without reconfiguration. We use MQTT , a lightweight machine-to-machine communication protocol, to send and receive data. The central data server (Lenovo ThinkServer,

[1] https://nikmart.github.io/WoZ-Way/

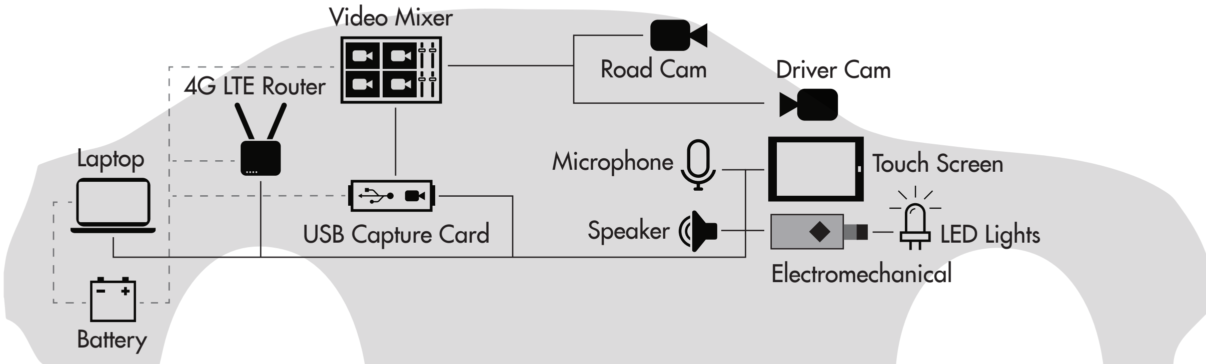

Figure 4. In car subsystem allowing for remote control of speech and electromecahnical interfaces along with live video and audio.

Ubuntu 14.04 LTS) runs a Mosquitto MQTT broker. [2] The server is located on a university campus and networked with a 1 Gbps Ethernet connection. In addition to managing the communication, all messages to the server are time-stamped and logged for later review.

Car Subsystem

A laptop computer is used inside the car to manage video, audio, and car data capture as well as to generate the text-to-speech messages received from the Wizard station. This computer also mediates communication to auxiliary interfaces. High speed (5 - 10 Mbps) internet is provided by a 4G LTE Wireless Router (Cradlepoint COR IBR600).

Video and Audio Streams

Our system implementation supports up to four video stream inputs, including video capture and screen capture. For most projects, we have found it necessary to have one view that includes the driver's hands, facial expressions, and body posture, and another that includes driving context through a road view. We usually have one or two further feeds dedicated to specific information such as the instrument cluster, a facial close-up, or an interface screen capture.

The video feeds are connected to a video multiviewer (GraVue MIO MVS-4HDMI), which synchronizes and stitches the video into a single 2x2 view. This stitched view is then connected to the computer via a video capture card (Inogeni 4K2USB3). Audio is captured using a high-quality microphone (CAD Audio U9 USB Condenser, Omni) mounted to the rear view mirror and directed toward drivers, to capture his or her speech and minimize road noise inside the car. The video and audio are streamed using a video chat client. We specifically chose Skype, as it has the ability to stream high quality (720p) video and audio, and dynamically prioritizes audio quality over video quality. Additionally, Skype is configured to automatically connect calls and start streaming video and audio without ringing, which allows automatic connection resurrection following inevitable on-road network disconnect events.

[2] http://mosquitto.org

Car Data Stream

Live car data such as speed, braking, and system status is captured from the car's built-in On Board Diagnostic (OBD) port. We capture data using a Bluetooth OBD logger (OpenXC compliant CrossChasm C5), which gives access to low-level, manufacturer specific data streams often not available in other OBD loggers. This device also allows for custom data filters and rate settings, allowing us to limit the amount of data captured to what we want to provide to the Wizard. The data is streamed over Bluetooth to a custom program running on the car laptop.

Input messages

Text-based messages are sent from the Wizard station to the car and are rendered to audible speech or on-screen messages by an in-car laptop. For the text-to-speech system, we leverage the built-in speech capabilities of MacOS. Sounds and spoken words are communicated through a wired, portable speaker (JBL Charge 2) placed in the car's cupholder. Using a separate speaker allows drivers to listen to music or use the in-car navigation as they normally would.

Auxiliary Interfaces

The Wizard can control custom interface prototypes using control messages sent from the Wizard interface via the laptop over WiFi. Screen-based interfaces can be prototyped using a tablet computer attached to the center stack of the car. The tablet also provides a built-in set of sensors such as GPS, acceleration, and orientation that can be streamed back to the Wizard interface, if desired. For custom electromechanical interfaces, such as ambient light controllers, we use microcontrollers with a USB serial interface to communicate data back and forth between the interface and the Wizard control station.

TEST DEPLOYMENTS

In order to explore the use of WoZ Way in real design contexts, we conducted three test deployments with designers and on-road drivers. In each of the studies, the designers acted as Wizards to interact with the drivers. Our tests include two proof-of-concept deployments, where we piloted novel in-car prototypes: 1) an interactive chatbot that converses with drivers during commutes, and 2) a touchscreen-based application of the car's center console. In our third deployment, we collaborated with an automotive industry research lab on an in-situ field study exploring the driving assistance of advanced Automatic Cruise Control (ACC) and lane-keeping systems. In the next sections, we describe how designers and researchers employed Woz Way for various purposes across these test deployments. These serve as examples of how the WoZ Way system can be used as a tool for observation and interaction prototyping.

Protocol

During all driving tests, the Wizards were free to interact with the drivers as they deemed appropriate for the specific test deployment. Drivers were made aware that there was a person controlling the interfaces. After every drive, we interviewed the Wizard for his or her experience using the system. We also interviewed the drivers, when available, about their experiences interacting with the speech system. We recorded video of the drivers, Wizards interacting at their stations, and screen captures of the Wizard interface. We also recorded audio of post-session interviews. These deployments were conducted under a research protocol (IRB-36970 Understanding on-road driving assistance) approved by our institutional review board.

Prototyping an Interactive Chatbot

We are currently working closely with a researcher who is exploring the commute as a space for mental wellness interventions. For one prototype interface, we are developing a speech-based chatbot for conducting therapeutic interviews with drivers. Drivers interact with the chatbot via speech while driving on their daily commute. The chatbot is controlled by a Wizard with experience conducting wellness and therapy interviews. We have setup WoZ Way as the prototyping platform for testing interactions between the chatbot and the driver, as well as a tool for collecting data to train natural language models for car-based wellness. We modified the audio setup such that the speech comes from the car's speakers and appears as if you were chatting with the car itself. We deployed the system to test its appropriateness for speech-based interaction prototyping during a short 10-minute test drive. The interface for this setup is shown in Figure 5.

The Wizard and the driver framed the discussion about food choices. During the course of the drive, the Wizard responded to the driver's answers and asked different types of questions to delve deeper into topics such as the driver's reasons for skipping meals, motivation to work hard, and goals in life. Our goal during the session was to explore how well the system would allow a chatbot designer to interact with the driver.

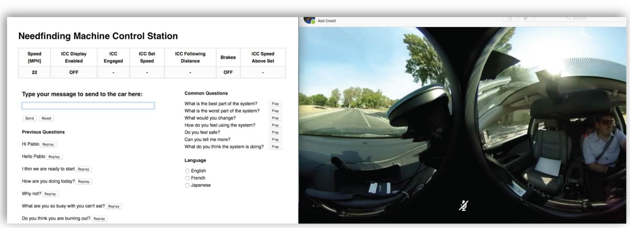

Figure 5. Screenshot of chatbot control interface.

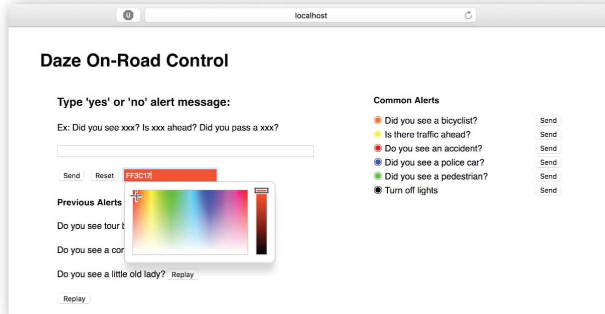

Figure 6. Screenshot of touchscreen message and light control interface.

Prototyping a Touchscreen Center Console Interface

In another research project, we are developing a touchscreen interface using a tablet computer to assess the Situation Awareness [14] of drivers on the road. During the drive, the Wizard controls pop-up messages that ask drivers questions about events that occur on the road, to see how well they notice their surroundings. For example, the Wizard might ask drivers if they passed a bicyclist or a construction zone. For this project, we also developed a simple set of ambient lights around the dashboard, to alert the driver that a question was waiting on the center console interface. These lights turn on when a new screen alert pops up and can glow specific colors determined by the Wizard, shown in Figure 6.

Our goal in this deployment was to test the ability of a remote Wizard to control interactive screen and electromechanical prototypes while also conducting a user test of a new application. We used the WoZ Way system to allow designers to observe the drive and to act as system Wizards to dynamically respond to on-road events without interfering with drivers. In a previous prototype of the situation awareness application, a designer sat in the back seat of the car to observe. While this setup works, the presence of the designer may heighten the awareness of the driver. Additionally, some of our researchers are prone to motion sickness while working on a laptop interface in a moving car. We modified the Wizard control interface for the current study to allow the Wizard to see the road, the driver's face, the driver's upper body and arms, and a screen capture of the application. We also added common alert messages with associated colors so that the Wizard could quickly ask if the driver saw common events like pedestrians. We used the text input area to allow the Wizard to create custom messages for unique events on the road. Finally, we added an RGB color picker to allow the Wizard to change the ambient light colors with relative ease.

During a 30-minute pilot, a Wizard spoke to a driver through the video chat interface to provide directions and to inform the driver about the situation awareness application features. The Wizard opted to speak directly to the driver, as it was easier to direct the driver along an ad hoc route. The Wizard followed the driver's location on the map and observed the surrounding area to choose locations for the driver to head based on where he thought interesting on-road events would occur.

Observing Use of Driving Assistance Systems

While the previous two test deployments were developed with design researchers working with our lab group, we also wanted to see how industry automotive designers and researchers could employ WoZ Way in the context of a real design challenge at an automotive research facility. Our partners are currently studying drivers' use of advanced cruise control (ACC) and lane-keeping systems. The designers were collecting real world usage logs, but they were interested in understanding drivers' in-the-moment experience. In addition, the group had an interest in designing speech-based interaction systems for use in the car. We co-developed a driving assistance case study to allow these researchers to remotely observe and interact with drivers. As the designers were primarily focused on understanding the current driving experience, this case study focused primarily on speech-based contextual inquiry. It serves as an example of the rich, ethnographic style of research that can be conducted using the WoZ Way system.

Vehicles Used

The study used four vehicles, across 12 different interactions. We conducted 10 sessions in either a 2016 Infiniti Q50 or Q50 Hybrid with Intelligent Cruise Control (ICC). Two pilot sessions were also conducted, one in a 2013 Tesla P85D with Autopilot and one in a Nissan Murano with ICC. The ACC+lane-keeping capabilities and the control interface of the hybrid and non-hybrid Infiniti Q50's were identical.

Wizards and Drivers

We recruited nine Wizards from the research facility staff. During the two pilot sessions, the first author acted as the Wizard. For the 10 sessions in the Infiniti Q50's, the Wizards were either designers, user researchers, or engineers currently working on aspects of new driving assistance features and in-car interfaces. All Wizards were interested in understanding the driver's experience using the ICC systems. Five Wizards had formal training with user research methods and have conducted formal user studies in that past. One Wizard participated in two sessions.

We also recruited 11 drivers from the automotive research facility to take test drives in the vehicle. These drivers were engineers, designers, and researchers working on new automotive interface and driving assistance systems. One driver participated in two sessions: one in English and one in French.

Driving Sessions

Drivers were invited to borrow one of the vehicles to either take home for the evening on their regular commute or for a 30–90-minute test drive. Drives ranged from 10–60 miles. Before their drive, drivers were told that the purpose of the session was to understand the driving assistance using the ACC+lane-keeping systems available in the car. They were told to drive safely, and as they normally would, but also to try the ACC+lane-keeping system when they felt it was safe to do so. Drivers were allowed to listen to music, use their phone, or have a passenger ride along. Two of the drivers were accompanied by a passenger.

Wizards interacted with the drivers through the text-to-speech system, asking questions about the drivers' experiences. The Wizard interface was modified for this study to include a live data stream including ACC+lane-keeping system state. We worked with our industry partners to develop a set of standard design research questions to such as "*Do you feel safe?*" or "*Can you tell me more?*" We also modified the speech system to allow French and Japanese researchers and designers to use the system.

FINDINGS

In this section, we discuss how the designers and researchers across all of our test deployments used the remote observation and interaction system. After each driving interaction, we conducted semi-structured interviews with the Wizards, and when possible, the drivers, about their experience using the system. We reviewed the interviews and have grouped our findings into four categories: system benefits, challenges, methodological discoveries, and implications for ethnography and design.

System Benefits

Reducing Interference with the Driver

We found that Wizards could react to on-road events that they observed without interfering with drivers. For example, during the touchscreen interface deployment, Wizards were often nervous about drivers' behaviors, much like a backseat driver might be. Since the Wizards were not physically present in the car, however, these actions did not influence or bias drivers' actions.

We have a similar anecdote from the driver's perspective during the chatbot deployment. The driver noted that talking to a machine voice allowed him to focus more on the road rather than needing to turn and acknowledge the person sitting next to him. This allowed him to speak more freely without his need for visual, social feedback from another person.

System Supports Flexible Use

Wizards were able to flexibly adapt WoZ Way to their own research goals. During the chatbot test, the researcher felt that WoZ Way allowed him to quickly explore the interaction possibilities of a chatbot in the car. He found the system useful for generating hypotheses for future studies and for generating ideas for autonomous chat algorithms.

The researcher in the touchscreen interface deployment found the system to be useful both for exploring how the app could interact with drivers and for running semi-controlled field studies.

In our experiences with industry designers, we found that Wizards with different backgrounds within the company used the system to help them answer specific questions that related to their own work. The system also allowed designers without formal user experience training to engage in exploring the driving assistance features. Designers with backgrounds developing control algorithms for advanced driving features noted how watching the interaction made them interested in making the automatic driving experience more human. These system designers often asked questions regarding the feel of the automatic speed adjustments during events such as lane changes or low-speed driving. Other designers working on in-car displays asked questions about the instrumentation in the car, what information the driver understood, or how the driver interacted with components such as the entertainment system. For example, when one driver turned on the radio, the Wizard asked, "*What do you listen to: radio, podcasts?*" Other researchers who were exploring interactions outside of the car even asked questions about how the driver interacted with bicyclists and pedestrians. Overall, the system allowed designers and researchers with varying backgrounds to investigate driving assistance and test new interaction prototypes.

Designers Improvise New Services On the Spot

We found that designers and researchers in the driving assistance deployment responded to drivers' experiences by prototyping new interactions as they came up during the drive. Some Wizards experimented with using WoZ Way to prototype an interactive user support system. For example, researchers who worked on advanced driving systems helped the drivers understand how the automated system worked when the drivers were confused. In other instances, drivers would request information from the Wizard about things relating to the drive itself. In one vivid example, a driver using GPS to get to a university campus was unable to find parking. The Wizard was familiar with the campus, and guided the driver to one of the visitor parking lots with turn-by-turn directions, using the live video feed to determine the car's location. The Wizard was even able to automatically pay the parking fee from a mobile app. From this emergent experience, the designer was able to prototype the interaction for a parking spot assistance system, a feature currently absent from most navigation apps.

Synchronized Data Streams Reduce Designer Workload

When asked how they used the Wizard interface, many Wizards found the video and data display to be useful for understanding the car's state. They remarked that it was nice to get a sense of what drivers might be able to see on the road and on their dashboard. By having all of the video, data, and controls in one interface, the Wizards felt they could control the inside of the car while experiencing the drive from the driver's point of view. Having data automatically synchronized and logged freed the Wizards from spending time to establish a ground level understanding of what was happening, like "*Is the ICC on?*" Wizards focused on asking higher level questions, such as "*Do you feel the ICC is more likely to fail with heavy traffic?*" or "*Do you feel the car prevented you from driving how you normally would?*"

Interaction Alleviates Concerns Over Surveillance

During our evaluation, the drives were explicitly framed as user experience studies. All the drivers knew that there was a person on the other end whose goal was to test new automotive user interfaces or to understand the driving experience. Even after understanding the data recording systems used in the car, most drivers did not voice concerns about privacy or being surveilled. If drivers did not want to answer a question, they seemed comfortable to stay silent. However, interactions were generally viewed positively and drivers answered questions openly. For example, during the chatbot deployment, the driver stated that speaking with the machine voice made him forget the person on the other end, and caused him to open up about his answers to the interview questions. Another driver in the driving assistance deployment said that the interaction he had, where the machine would respond to events on the road and inquire more about the driver's opinions, made him feel that his feedback might be heard by someone who may actually be able to change the experience for the better.

In another session, the driver initially showed hesitancy in being recorded, asking "*Are you guys watching me?*" The Wizard replied, "*The cameras enable my contextual reasoning.*" This ended up being a very chatty session. After becoming more comfortable with the interaction during the drive, the driver needed help parking and the Wizard assisted. The driver even began to thank the system for helping her navigate to a location she was unaware of. This provides an example of how interacting with drivers, rather than just monitoring them, can go beyond disclosure to help ease privacy concerns; the interaction helps to frame the purpose of the data system as a collaborative design tool rather than as spyware.

Remote Interaction Reduces Logistical Headaches

During our drives, we avoided the logistical challenges of driving along with people on their daily commutes. Although setting up the system can take some time, it gives Wizards more freedom to be a part of the drive from their own location. Many of our drives began or ended at drivers' homes, sometimes up to 60 miles from designers' offices. Using WoZ Way allowed designers to observe and interact in these everyday drives without requiring the complicated planning associated with getting researchers to meet up at someone's home, or arranging chase vehicles to take researchers back home after the fact. This reduced logistical burden made it possible to do more runs and observe more people.

System Challenges

Dangers of Remote Interaction

Wizards across all of the test deployments felt that they needed to alter their behavior based on what drivers were doing on the road, so they would not distract the drivers too much. Specifically, during taxing or dangerous events for drivers, Wizards often held off on planned interactions. They were often challenged to find the appropriate time to ask about the experience. One Wizard noted after a cut-off event that she tried asking a question when the driver was overloaded and needed to wait until the driver had calmed down to ask the question again. Although the driver was able to ignore the question and focus on driving, the Wizard would have liked to understand what moments were, and were not, appropriate to interact with the driver. We also saw this in our interaction prototyping deployments. Wizards would often cringe if they sent something at the wrong moment as they were asking questions with the chatbot or controlling the touchscreen.

Throughout our testing, no prototyping or observation sessions needed to be stopped. While drivers did note that some interactions from the speech system were awkward, these did not inhibit the driver from safely operating the car. Designer's who had an awkward interaction often waited for a better moment and then continued their testing. Still, this suggests further research about how designers should handle these situations.

WoZ Way is Network Dependent

Wizards generally did not notice significant latency from the time they sent a message to hearing it or seeing an interface change in the car (< 1s). However, in two sessions, heavy network loads caused the video and data link to be severely delayed (> 5s) or to completely disconnect for several minutes. This was associated with dense, slow-moving traffic; it is possible that cellular towers are impacted by having too many cars in one location. When the system is fully disconnected, there is nothing the designer can do but wait for a better signal and for the car to reconnect. This causes gaps in real-time understanding of the driver's experience, loss of control of in-car interface, and can cause breakdown in the interaction, as the driver is often unaware the system has disconnected. During sessions with poor video quality or a loss of car data, the Wizard often reverted to asking low-level system questions, like what speed the driver was going. During one session with very poor video quality, the Wizard had the driver conduct a speak-aloud protocol to describe what was happening. Although this worked for one session, it speaks to the importance of having high-quality, real-time data streams and for designing robust systems with automatic reconnection.

Methodological Discoveries

Remote Observation is Different from Backseat Observation

Although designers are virtually riding along with drivers, we found a number of differences from having designers in the car with drivers. Designers were better able to understand the single-driver experience. Remote designers also had a better view of the driver than is available from the passenger or rear seat, and without the awkward overhead of trying to remain invisible while being hosted as a guest of the driver. The researcher in the touchscreen interface deployment stated that he "*felt like a drone pilot or an air traffic controller.*" The ability to see many views and data streams at once was something he could not do before.

Interacting remotely also changed the process used by the designer while observing and interacting with drivers. A design anthropologist in the driving assistance deployment noted how she did not feel the need to make small talk, asking about the driver's day or her plans for the evening. Instead, she either asked focused questions or sat back and watched the drive in silence, observing the driver and the surrounding context without interruption. The Wizard felt that this allowed her to think more about what interactions were happening rather than thinking of what to say next. This allowed her to more readily understand and engage with the driver's on-road experience.

From the drivers' perspectives, their interactions with Wizards through the machine interface gave them more freedom to not answer questions. For example, during the driving experience studies, some drivers did not answer questions because they were focused on the driving task. Other drivers did not respond to questions they were not comfortable answering. Still, many drivers forgot that the car interfaces were controlled by a person and interacted as if it were a machine. The removed social presence of the designer gave more room for the drivers to act more naturally while driving.

Delays Disrupt Fluency but Increase Disclosure

Although the relay of messages or control commands was near real-time, Wizards were often limited by their typing speed during speech-based interactions. This altered the interaction between the Wizards and drivers. During the chatbot and the driving assistance deployments, Wizards discussed how they would begin writing a new question only to have driver change the topic. This caused the conversation to lose fluency as the Wizard needed time to write a new question. Drivers noted how long pauses broke the flow of conversation. However, this also made them feel more like they were talking to a machine. Often, the long silences led the drivers to feel as if they should expand more on what they were talking about. Although this is partly a challenge of using a typing-based system, we found that the natural elicitation from awkward silences could be lead to deeper discussion of certain topics.

DISCUSSION

Based on the development of WoZ Way and our evaluation with designers and researchers, we believe our system enables many new opportunities for remote observation and interaction during the development of interactive automotive technologies. During our deployments, these professionals were able to explore a wide variety of situated real-world driving experiences. They then employed a variety of improvisational interaction techniques to better understand drivers' experiences. By blending rich, social interaction and web-like data collection, WoZ Way allows for new forms of computer-supported design work for interactive, physical systems in-the-world. This contingent interaction model can support many aspects of the interaction design process.

Implications for Ethnography

Our test deployments captured all of the spontaneity and messiness of real-road drives. They included drivers being cut off, getting stuck in traffic jams, listening to music, interacting with passengers, and getting lost. The richness of these real-world occurrences allowed the designers to see a breadth of driving assistance opportunities that would not have been present in a controlled environment.

The real-time capabilities of the system allowed drivers to respond immediately to quickly changing contexts and inquire about relevant and salient experiences a person might have. During the touchscreen interface deployment, the designer was able to ask about the app usage and get feedback right away, which allowed him to further guide the user test. In another example from the driving assistance deployment, the driver of the Tesla P85D heard a squeak on the door panel and began prodding the various panels in the car. The remote designer asked, "*How is the build quality?*" to which the driver responded "*Not very good*" and explained how the panels should not make a "*quack*" noise in such a high-end vehicle. This interaction showed how even when the focus of the driving study is to explore the driving assistance capabilities, the Wizard is also able to respond to interesting events in the car. This shows the opportunity for designers to understand the holistic product experience and perform contextual interviews in real-time.

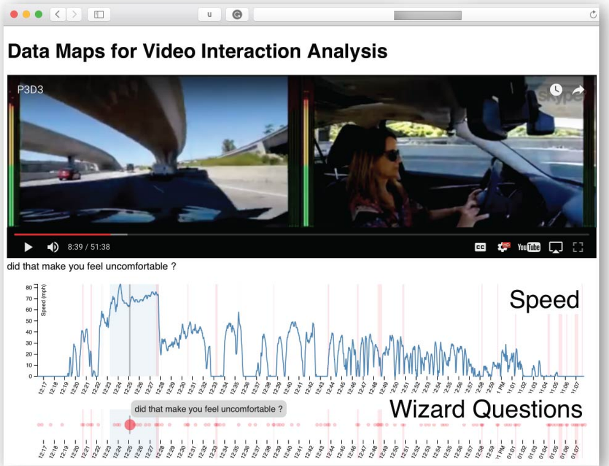

Figure 7. Screenshot of video interaction interface created with WoZ Way data.

By not being in the car, the designers felt more anonymous and removed, reducing social pressure in the conversation. During the chatbot study, the premise of acting like a chatbot pushed the designer to ask more and more personal questions. We saw a similar pattern in the driving assistance deployment. One Wizard suggested that "*The system could be useful for finding deep needs, or deep desires.*" Wizards often asked questions such as"*What new driving pleasure could we imagine in the future?*" or "*Do you think a machine could be better than man?*"

Another designer found that acting through the machine could allow many designers to interact through the system over time with the same driver. This would allow multiple perspectives while having the speech system appear to be stable across interactions with a driver. The designer also suggested that the system could be used for longer term studies and that it would reduce the need to plan drive-along style sessions.

Finally, the synchronized data collected from the driving sessions can be used for detailed video interaction analysis. We have created an interactive data analysis interface, shown in Figure 7, with the video, car speed, and designer questions. This interface allows designers to review drives by selecting interesting points in the data, automatically jumping to those moments in the video. This allows designers to use the collected data as a means to review the qualitative driver experience.

Implications for Design

With real-time control of in-car interfaces, designers are able to prototype new interactions based on the behavior of the driver and events on the road. The ability to control interfaces remotely allows designers new opportunities for exploring product usage in the real world. The chatbot and touchscreen deployments specifically intended to show the responsive interaction prototyping capabilities of the WoZ Way system. The Wizard in the chatbot deployment found that he was able to actively respond during his interview with the driver. During the touchscreen interface deployment, the Wizard was able to rapidly respond to events on the road and test new interactions with the interface. This is different from testing a pre-programmed app, as it allowed the designer to test new ideas improvisationally. For example, near the end of the drive, the Wizard was interested in how the ambient lights caused the driver to instantly focus his attention toward the touchscreen. He changed the color of the interface without a pop-up message and saw that, indeed, the ambient lights caused a conditioned response for the driver to look at the screen.

One aspect of our system that we would like to address is the difference between interaction and monitoring. As data logging becomes more pervasive in our daily interactions with technology, questions often arise about the ethical use of the collected information. Although our system does allow for remote observation and logging of people's interactions, which can present privacy concerns, we place a focus on facilitating *interactions* between designers and drivers. These interactions reframe the intent of the observation to the design of better product experiences and invite drivers to be active, collaborative participants in the design process. Brereton et al. argue that engagement and reciprocity are critical to conducting ethnographically driven design work, especially with remote populations [2]. While their work explores engagements with aboriginal populations, it suggests how we can use interaction to positively frame remote design observation and prototyping.

Opportunities for use in CSCW work

The unique, enabling features of the WoZ Way system can influence the overall design process of interactive automotive systems in a number of ways.

Evaluating Prototypes

Usability researchers can evaluate prototypes in real-world contexts and gather both qualitative and quantitative data about a person's experience. Researchers can better understand causality and rationale for various behaviors by observing usability data and contextual inquiry.

Designing Interactions

Designers can quickly explore the interaction design space of new technologies without investing significant time toward algorithm development. Interactions can move from improvised to more supervised over time. The underlying computing architecture of the system can easily extend to broader graphical or physical interfaces.

Group Studies

By interacting remotely and not occupying a seat, researchers and designers can better explore how groups interact within the car. This can be useful for studies of families on road trips, coworkers carpooling, and passengers using ride-sharing services.

Mixed Methods Research

The use of WoZ Way enables designers and researchers to employ many types of research methods for their work. The in-situ observation and interaction provides the designer with rich moment-to-moment understanding. Data logs and video recording from the session then allow for further data and video interaction analysis.

Studying Demographics/Individual Differences
It is possible to work across demographics and in different locations. With fast internet, the system architecture can be used for conducting studies between different states or countries. For example, we have be able to connect designers in Europe to drivers in California. It is also possible to focus on individual differences between people. This can provide a rich and nuanced understanding of users that can lead to the basis for adaptable systems.

Longitudinal Studies Over Time
It is possible to embed the features for remote observation and interaction into the car itself. More generally, the architecture of WoZ Way is similar to that of connected devices, which is an indicator that the observations and interventions enabled by WoZ Way can be inherent features of connected devices. This can allow exploration of people's experiences over longer time periods. Since designers simply need to "log in" remotely, rather than be present to interact with someone, they can more readily interact over weeks or months. This can help designers to develop adaptive systems and to see how experiences change over time.

Future Work
While we have shown several specific uses for a WoZ system within the context of the remote car, we see many future avenues for exploring these forms of systems in general. For instance, the Wizard interface can take on different configurations and features to support the specific workflows of designers and researchers. For example, note taking capabilities could be added to support in-the-moment learning. We are also interested in new forms of real-time data visualization that would better support working with the live data streams.

Finally, there are many open questions about best practices for remote WoZ interaction in the car. For example, what latency still allows smooth interaction? What aspects of the road or driver state can signal a good time for the Wizard to interact? In what other contexts can WoZ systems be used remotely? Just as WoZ Way borrowed insights and practices from other ubicomp design research systems, the discoveries made in the in-vehicle environment might inform practices outside the car. We can imagine different deployments exploring interactive technologies in the home or at work and we are excited to support designers in the development of new interactive computing contexts.

CONCLUSION
As computing applications spread beyond the workplace and home, there is a need to support designers in understanding people and creating new interactions in transitional environments like the car. By creating tools to give designers a rich understanding of users in-situ, we enable the invention of interactive systems that make the most of the environmental, system, and social contexts that users find themselves in every day. In this systems paper, we have introduced WoZ Way as an interaction design system for understanding and prototyping driving interfaces during real-world driving. Through our deployment with professional automotive designers, we have found opportunities for real-time, remote observation and interaction during the design process. Our primary contribution is showing how such remote interaction and observation systems can enable new capabilities for user research and design prototyping.

As computing becomes ever more prevalent and objects become ever more imbued with interactive and adaptive capabilities, it will be increasingly important to explore design support tools for understanding and creating these experiences. A system such as WoZ Way can aid in the design process and help designers and researchers to better understand people and design exciting new experiences. Moving forward, we imagine that interactive objects will serve both as designed products and also as design tools. As tools, they can facilitate an ongoing conversation between designers and people. Through this conversation, we anticipate that designers will be able to better understand people's changing needs and actively design useful and delightful product experiences.

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