Investigating and Developing Methods for Traditional Participant-based Data Collection with Remote Experimenters

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16. Abstract
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Abstract

This project investigated and developed methods and technologies to allow experimenters to conduct and monitor data collection from a remote location. The technologies developed consist of a desktop application that allows researchers to view the vehicle cabin and various vehicle parameters (like speed, acceleration, etc.) in real time. Physically removing researchers from the vehicle during experiments can increase realism and offer naturalistic observations in traditional, experimenter-conducted studies. The remote experimentation methods and technologies developed can be particularly helpful for studying automated driving by creating a more natural environment while still maintaining oversight and control of the experiment.

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Introduction

This project was borne out of the COVID-19 pandemic, which caused massive disruptions to human subjects experiments at Virginia Tech Transportation Institute (VTTI) and around the world. During that time, when it was completely unclear how safe it would be to perform experiments in-person again, the research team developed a concept for performing experiments remotely.

Although this is not a novel concept by any means, the transportation research space features several unique challenges for this model of research. For instance, while lab experiments can generally be relatively easily updated to ensure that experimenters and participants remain at a safe distance from each other, typical automotive systems research may require driving an instrumented vehicle to collect data. This usually requires experimenters to be in the vehicle alongside participants to explain tasks, oversee task completion, administer questionnaires, manipulate vehicle systems, etc.

The research team's vision for a set of remote experimentation tools took into account the unique challenges presented by study types common to VTTI's work packages. These tools would require remote, real-time viewing of vehicle information such as speed, acceleration, vehicle subsystems state, and also a way of viewing and interacting with participants to describe tasks, monitor participant progress, and administer questionnaires upon task completion.

As the research team developed this remote experimenter concept, it became clear that although this was initially thought of as a COVID-19 mitigation, the idea of a remote experimenter presented a number of benefits for some study types over the traditional in-vehicle experimenter paradigm. Removing the experimenter from the vehicle has the potential to elicit more natural behavior from participants, as no one is there physically watching them, potentially affecting their actions.

Certain types of studies—for instance, those observing natural driver behavior with late-stage prototype features—could greatly benefit from a more naturalistic study of driver behavior. Similarly, automated driving system (ADS) technologies could benefit from a remote-first experimentation method. Removing the experimenter makes it possible to isolate participants in a real or simulated ADS-equipped vehicle, more closely replicating a production ADS experience. This prevents participants from relying on experimenters as a perceived "safety net" in the vehicle and may help elicit more natural responses as they use and interact with an ADS. This principle is guided by a simple example: participants riding in an "ADS-equipped vehicle" *with* an experimenter are likely to feel an additional layer of comfort being with someone who is familiar with the vehicle and ostensibly responsible for their safety. Those who ride alone in the vehicle are without this layer of comfort, as they would be in a real-world, production ADS-equipped vehicle.

Even in studies where more naturalistic behavior is a benefit to the data collected, it is still important for researchers to closely monitor participant behavior and the progression of the experiment. This monitoring is also a safety benefit for participants, as researchers serve as a second set of eyes in the vehicle. For this reason, additional tools were needed to enable the type of remote experimentation that the research team developed.

Method

In order to fully develop the remote experimenter concept and related technologies, a series of tasks were devised to ensure the research team was creating tools that could support a broad array of research while being useful for the specific kinds of research the team typically engages in.

Protocol Review and Requirements Creation

The first of these tasks was a review of internal VTTI research protocols. These protocols were primarily studies of advanced vehicle systems and interfaces, with an emphasis on measuring driver performance using these systems. This review focused on developing a list of common requirements that any remote experimenter tools would need to support:

1) Two-way communication with participants
    a. Audio required
    b. Video preferred (multiple vehicle views if possible)
    c. Screen sharing preferred (to show supporting diagrams for tasks or administering questionnaires)
2) Data monitoring (speed, acceleration, vehicle subsystem status) from the vehicle in real time
3) Experiment information timestamping (task number, trial number)
4) Vehicle localization on a map (for monitoring study progress)
5) Remote vehicle system control
6) Low-latency communications for safety critical applications
7) personally identifiable information (PII) protection
8) Cost-effective
9) Wide coverage area (communications over 4G/LTE or 5G)

After this review, the research team developed a mock study protocol that could be used to assess the suitability of tools for remote experimentation. This mock protocol (see Appendix) was designed to simulate common study designs used at VTTI.

The protocol featured a participant driving to a set location from VTTI while completing tasks when prompted by the experimenter. One task developed was based on the Automotive Alliance for Innovation's reference radio tuning task. This requires drivers to tune between stations, requiring a minimum number of interactions with the center stack. The second task required participants to make a lane change upon command, a common request when doing in-person driving experiments. These tasks provide a way of evaluating the ease of issuing commands and monitoring task progress consistently across potential remote experimentation setups.

After development of this mock protocol, the research team submitted the plan to VTTI's internal safety committee for feedback. Overall, feedback was positive, and some changes were incorporated into the protocol as a result. In particular, feedback suggested that wording on task prompts incorporate safety-dependent language—i.e., when requesting the participant make a lane change, start the prompt with "when safe to do so." Since the experimenter has limited situational awareness of the vehicle, determining the safe time to execute a command falls upon the participant. The adjusted wording prompts participants to ensure the situation is suitable for the requested maneuver before beginning. With these minor changes, the safety committee approved the protocol.

The next hurdle for this research study involved the ambiguity of whether the research qualified as "human subjects research" per the Virginia Tech Institutional Review Board (IRB). If so, a full IRB application would be required before testing of any remote experimenter tools could begin. Lengthy discussions were held with VTTI's internal IRB expert, and a non-human factors research determination form was developed to exempt these activities from needing IRB approval. The IRB agreed that our activities fell outside of true human subjects research and more into product evaluation, and therefore development of a full IRB application was unnecessary.

Market Scan

The research team evaluated video conferencing tools and mobile computers to understand their suitability for use in remote experimentation. Initial tests simply used Zoom videoconferencing software running on an iPad. VTTI employees served as mock "participants" to undergo the mock protocol and provide feedback on interacting through the iPad via Zoom. Various routes covering the New River Valley, within approximately 20 miles of VTTI, were used in this testing to evaluate potential connectivity loss causing interruptions in communication.

Researchers did learn that Zoom was a convenient communication tool, particularly for research, as it enabled them to share questionnaires and Likert scales (when the vehicle was stationary) to collect data from the "participants." Connectivity could be an issue for certain routes, and once the call was lost it was impossible to re-initiate the call without requiring something from the driver, and was slightly difficult once the driver was stopped and able to restart the call.

Simple videoconferencing, however, did not provide the additional information previously identified to enable proper monitoring of participants as they completed their routes. Information such as speed, acceleration, and GPS position are not available through Zoom or through any other service integrated with videoconferencing features.

The research team also investigated so-called remote operation platforms, such as that formerly sold by Designated Driver (https://www.wired.com/story/designated-driver-teleoperations-self-driving-cars/). This class of tool provides much greater situational awareness, with multiple camera views available to the remote user, and includes vehicle information such as speed, acceleration, and GPS position. Such systems are incredibly expensive, however, and were quickly dismissed by the research team due to their costs.

Gap Assessment

After the market assessment, the research team performed a "gap assessment" to determine in which areas the currently available tools and systems fell short of the features required to enable effective remote experimentation. Off-the-shelf videoconferencing solutions like Zoom come with some concerns over privacy and PII since they require that all users' data be streamed through their own servers. For research where driver privacy is required, this made Zoom unappealing. Additionally, the Zoom service is not free, and maintaining subscriptions for projects would be an unwelcome financial and management burden.

As an alternative, the open-source videoconferencing tool Jitsi was identified (Jitsi, 2021). Jitsi can be hosted by VTTI, ensuring that video data from participants never exits VTTI's networks. It also features peer-to-peer conferencing, which routes video/audio directly between users instead of through a central server, reducing latency.

No tools identified by the research team were able to integrate a map view, vehicle data, and videoconferencing into a single interface. As these requirements were identified early on during protocol evaluations, the research team decided that off-the-shelf solutions would not be capable of meeting all the needs of a remote experimenter.

Technology Development

After determining that no off-the-shelf tools currently available would meet all requirements, the research team began developing their own tool to integrate all of the required features into a single application. This development was greatly aided by two open-source projects initially developed by Uber for their autonomous vehicle division: Streetscape.gl and the XVIZ data specification framework.

The Streetscape.gl framework, designed for visualizing data from ADS-equipped vehicles, allowed the research team to track the vehicle on a map and create widgets and graphs of vehicle data that could be updated in real time. This enables potential remote experimenters to monitor a participant's location, determine whether they were obeying the speed limit, or whether they were performing any hard stops or accelerations. Additionally, as this framework was designed for monitoring ADS-equipped vehicles in real time, it is incredibly performant. This means that data updates can be quickly visualized to provide experimenters with near real-time data from the vehicle.

The open source MQTT protocol was used for data transmission, particularly the Paho-MQTT package for Python. This data transport protocol is extremely simple to set up and the data broker can be hosted on-premises, ensuring that PII does not leave VTTI's servers, a certain requirement for any potential IRB applications making use of remote experimentation tools. Additionally, this setup supports encrypted communications via TLS (Transport Layer Security), another layer of protection for subject data. Lastly, MQTT proved to provide sufficient performance to enable real-time monitoring of vehicle data. Our testing showed that end-to-end latency for data was typically less than 100 ms from the vehicle to the remote experimenter console's screen.

Experimenter Review

Once the initial prototype (application to display vehicle data and position, method of collecting and transporting data for visualization) was developed, the research team reached out to seasoned experimenters within VTTI to demonstrate the capabilities of the developed software. These experimenters used the remote experimenter workstation to monitor a mock study session live and provided feedback on the interface and capabilities based on their own experience.

In general, researchers were positive about the potential of the software for enabling remote experimentation, but there was some feedback provided to improve the capabilities. First, there are limitations to the software developed. As it stands, it is not possible to change which data can be accessed remotely—the variables that are enabled at the start of the session are the only ones can be visualized and monitored. Second, though the experimenters did like that they could see the vehicle's location on a map, they indicated it would be useful to visualize the intended route for the study, for instance via a colored overlay along the appropriate roadways. And lastly, experimenters identified a need for the ability to interact with the study vehicle via the interface, in order to, for instance, change task numbers or system states within the vehicle.

Results

Final User Interface

The final user interface is shown in Figure 1 below. This screenshot was taken from a live recording of vehicle operation and demonstrates the majority of the supported features. As seen in the screenshot, video from the vehicle can be streamed to experimenters so they can monitor the experiment's progress. Graphs of variables are configurable based on how the vehicle is configured, and data latency is calculated in real time so that experimenters can determine if the data they are receiving is stale. The map view on the right shows the active GPS position of the vehicle itself. Controls shown in the software can be configured as needed for each project. Features not shown include the ability to configure which data sources are used to populate the charts/widgets.

Figure 1. EagleEye Remote Experimenter Tool.

Latencies for video, audio, and data were typically less than 100 ms end-to-end, but with occasional spikes or loss of communication. This proved to be useable as a real-time monitoring tool; however, due to the periodic losses of communication, the research team was not comfortable using the system where safety critical intervention was necessary.

Test Study

To fully test the software, the system was used for a research study performed by a graduate student at Virginia Tech. This research study was intended to gather feedback from blind and low-vision participants on human machine interfaces for ADS-equipped vehicles (Bloomquist 2023). The student needed to remotely monitor and interact with subjects in a simulated ADS-equipped vehicle environment (the vehicle was manually driven but subjects were allowed to believe the driver was only a safety driver). By removing the experimenter from the vehicle, study participants had a heightened sense of being alone in the vehicle, allowing more realism and increasing study efficacy.

Overall, the remote experimenter software enabled the research study to be completed successfully. In general, system performance was robust with few issues caused by loss of connection with the vehicle. The student researcher was able to monitor study progress and interact with participants in real time via an integrated Jitsi call. For one session, the video call was lost and was unable to be recovered, but largely the system functioned as intended.

Discussion

The research team discovered that particular emphasis must be placed on participant safety during protocol development as it relates to potential distraction. As the researcher will not be present to closely monitor the driving environment and driver workload, what would normally seem to be simple instructions for tasks can in practice be more difficult to convey or implement via the remote experimenter model.

Additionally, this type of tool is not suitable for every form of automotive research. Particularly, research involving surprise events or potentially safety critical interventions are not well-suited for the remote experimenter model. Wireless communications links that enable remote monitoring, such as those implemented for this project, are currently not robust enough to enable this kind of research using these tools. This tool is well-suited for human behavioral research, where simply monitoring participant behavior remotely increases realism or provides other benefits to the study, such as the study outlined in the Test Study section.

Based on the research team's experiences so far, additional development is needed to fully realize the potential for the remote experimenter tool. For instance, incorporating study routes and waypoint notifications would greatly enhance the tool's overall usefulness.

Conclusions and Recommendations

When designing experimental protocols with remote experimentation in mind, simpler protocols are generally better. Any complications can result in participant confusion and potentially adverse safety outcomes (i.e., distraction, given the study environment). Additionally, particular emphasis should be placed on route selection and prioritizing routes with excellent cellular service. This does limit the environments in which studies using the tool can be conducted, but ultimately remote monitoring relies on sufficient 4G/5G/LTE network coverage for low resolution video and audio transmission (data transmission is less problematic and can accommodate occasional service dropouts).

The tools developed by the research team have the potential to enable new kinds of research and improve fidelity for certain kinds of existing research by removing the experimenter from the vehicle. In theory, this could result in more natural participant behavior. This could be particularly useful for studying subject interactions within an ADS-equipped vehicle context, but certainly other research areas would benefit as well.

Additional Products

Education and Workforce Development Products

This project enabled the research of Eric Bloomquist, a graduate student at Virginia Tech. Jacob Walters, who was a community college student during the project, also worked on this project.

Technology Transfer Products

The research team presented the project to a Transportation Research Board panel, explaining how it could help enable research to continue during pandemics where in-person interaction is risky for both experimenters and research personnel.

The research team presented to VTTI's monthly Principal Investigator's forum to help researchers understand this new capability (and whether it could be useful for their research studies) and to give them an opportunity to provide feedback. Researchers presented to the NSTSCE committee as well to gather additional feedback on features desirable for the remote experimenter tools under development.

Some of the software developed for this project has already been incorporated into other research studies, one sponsored by the Virginia Commonwealth Cyber Initiative and the other sponsored by the Federal Highway Administration.

Data Products

A version of the research tool that demonstrates basic functionality has been uploaded to the Safe-D Dataverse. The uploaded application consists of the JavaScript and Python source code needed to visualize data. A vehicle "simulator" application is included that will play back real-time data for the application to consume is also included. To make use of MQTT or remote data viewing capabilities, users will need to create and host their own data broker and configure the application to use that broker.

https://doi.org/10.15787/VTT1/HEDSB6

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Appendix

Mock Study Protocol

<u>Remote Experimenter Protocol</u>

<u>~5 minutes before assistant's scheduled start time, start Zoom call on iPad in Host Vehicle with video DISABLED</u>

1) Introduce the assistant to the test vehicle, while maintaining a safe distance and point out the following:

- Seat adjustments
- Mirrors and mirror adjustments
- Steering Wheel adjustments
- HV/AC
- iPad for remote experimenter call and instructions

2) Transition to Remote Experimenter Role

"This iPad will serve as communication for us on your drive today and will include instructions for the tasks we have planned for you and will serve as two-way communication for us. It will host a direct audio/video call with me during your drive today. I will provide instructions and answer questions via this iPad."

Once the assistant is settled in the vehicle inform them that the zoom call is active, and you will now return to your office and continue the session remotely.

"The call between this vehicle and the computer in my office has already been established, I'm now going to continue the session with you remotely, via the Zoom Audio/Video Call."

3) Return to office and confirm two-way communication with assistant

"Hello, this is [experimenter], I'll be interacting with you via this iPad for the remainder of your assistance today. For the first task, you'll be driving back and forth to campus from VTTI.

4) Introduce the assistant to the proposed study tasks:

a. Radio Tune Task:

This is a secondary task that we will ask you to complete during a portion of your drive today. The goal is to tune the car's radio to the designated band and station. Let's practice this now. First let's ensure that the source is the radio, and that the volume is at the correct level. Some of the stations that we will tune to today aren't active, so we'll keep the volume low to avoid static. Please always verbally confirm when your radio tuning task is complete by saying "Done."

Ensure volume set to appropriate level and set the radio to FM 92.3 to begin the practice task.

We are currently set to FM 92.3 to start the practice, let's have you tune to FM 99.1. To do that press the "Tune" button and then press the right arrows button until you reach 99.1.

Once the task is complete, reset to 92.3. Leave the radio on FM 92.3.

b. Lane Change Task:

While you are navigating between the different destinations, I will ask you to perform lane changes at certain points in time. It is very important to keep in mind that any and all lane changes should only be made when it is safe to do so in the context of the driving environment and surrounding traffic. To prompt you to make a lane change, I will say, remotely from the iPad, "When safe to do so, please make a lane change." You are free to make a lane change at any point after that, given that it is safe and appropriate to do so. Please remember that this vehicle is equipped with a blind spot monitor [point out the indicator led]. This can help identify vehicles in the blind spot, but it should not be relied on as your only source of confirmation as to whether a lane change is currently appropriate or safe, so please make mirror and/or over-the-shoulder glances as you normally would when checking that it is safe to change lanes. Please verbally confirm when your lane change is complete by saying "Done."

Monitor the HV travel via software and be ready to respond to questions/needs.

When first stop is reached:

"I'm now going to ask you some questions about the task and the study so far. Please choose a number that aligns with your level of agreement to the statements that I read, once I have recorded your responses, we'll move on to the second task."

"Thank you for your input , let's now travel to back to VTTI As before, please follow the vehicles turn-by-turn directions and park in the parking lot once there. Once you are parked, confirm that verbally with me over this call. Once you are parked, I will resume video and ask you some questions about the directions and the trip in general. We do ask that while you are on public roads that you follow all traffic laws and drive in a safe and responsible manner. Do you have any questions?"

Monitor the HV travel via software and be ready to respond to participant questions/needs.

Once the assistant confirms they have reached VTTI, resume video on the Zoom Call

Monitor the HV travel via software and be ready to respond to participant questions/needs.

Once the participant confirms they have reached VTTI, resume video on the Zoom Call

"I'm now going to ask you some questions about the task and the study so far. Please choose a number that aligns with your level of agreement to the statements that I read, once I have

recorded your responses, that will conclude the study today."

"Thank you for your input. Your assistance is now complete.

5) Exit your office, and return to the Host Vehicle

a. Power down the car
b. Remove the Hard Drive
c. Make note of the fuel level of the vehicle, if needed, request fueling.
d. Return HV to appropriate parking space
e. Ingest Data