How to Maximize Trust in Autonomous Driving

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Abstract—Integrating semi-autonomous and autonomous vehicles into society requires optimizing the level of trust between driver and vehicle. Human trust varies as driving circumstances become more or less difficult and vary person to person. As such, this capstone project aimed to study and enhance human trust of semi-autonomous vehicles. We conducted trials with human participants using driving simulators, physiological sensors, and surveys to determine trust levels in relation to driving scenarios. Results include the relationships between factors such as alarms and weather conditions on driving trust as well as further experimentation on optimal pathing and route-planning to optimize trust.

I. Introduction

In 2016 the University of Virginia began semi-autonomous driving research and acquired a driving simulator, physiological sensors, and software required to conduct experiments. Since then, the research team has acquired funding from Toyota, Lockheed Martin, and the NSF under grant #1755784 (CPS: Cognitive Trust in Human-Autonomous Vehicle Interactions) [1]. The Force Dynamics 401CR driving simulator used by the research team provides a four-axis motion platform that simulations the motion of an actual vehicle. The driving simulator runs PreScan software which has been programmed by the research team to simulate semi-autonomous driving behavior. Physiological sensors including a Shimmer3 EMG (Electromyogram) sensor, a Shimmer3 ECG (Electrocardiogram) sensor, a Shimmer3 GSR (galvanic skin response) sensor, and Tobii Pro Eye-tracking Glasses. These sensors have been synchronized with incoming driving data from the simulator using a software called iMotions Biometric Research Platform. iMotions allows for multi-modal data such as biometric sensors, eye tracking, and user surveys to be time-stamped, synchronized, and visualized for every participant.

Fig 1. The Force Dynamics Driving Simulator

Fig 2. PreScan Scenario

We conducted human subject experiments (under UVA IRB-HSR protocol #20606) to collect data and better understand how semi-autonomous driving relates to trust. Participants typically spent one to three hours depending on the nature of the specific driving routes to complete all experiments. Participants conducted their experiments in Rice Hall 020, University of Virginia in the driving simulator through different simulated scenarios. The participants press buttons on the steering wheel that have been programmed to increase or decrease their perceived level of trust of the autonomous system.

Participants' use of physiological sensors including eye-tracking glasses, GSR, and EMG sensors also provide data such as perspiration, skin conductivity, and heart rate that can help deduce stress and trust levels. In addition, surveys were given to the participants between trials. This data collection aimed to identify the key factors being trust changes and lead to improvements in self-driving technology integration.

Fig 3.   iMotions View of Synchronized Data

II.   DESIGN PROCESS

Each tool we used in this research offered us degrees of flexibility. We used the Force Dynamics Driving Simulator because it offered the most immersive experience for the participants and could be programmed using different softwares and remapping buttons. PreScan allowed us to not only remap controls, but create the tracks and obstacles for participants to drive through as well as implement lane-changing and self-driving algorithms for the autonomous mode of driving.
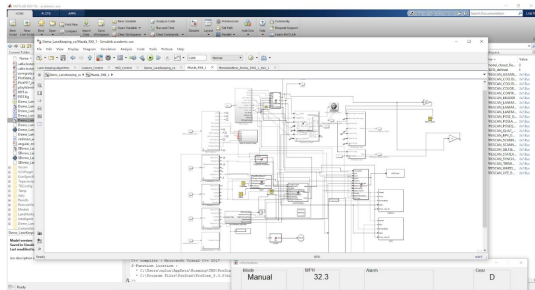

Fig 4. PreScan Simulink Programming

We elected to use iMotions because it allowed us to combine driving simulator data transmitted over UDP and formatted through a custom API. This allowed us to synchronize and see in real-time a participant's changing heart rate or GSR levels as they moved or looked at something. Having data from the driving simulator synchronized allowed us to correlate certain physiological responses with things like breaking, accelerating, or changing between autonomous and manual driving. All driving related data including throttle, brake, speed, trust, mode, and obstacle being encountered were synchronized and collected as well.

We chose to study a participant's trust as it related to unideal driving conditions -- these included poor weather conditions/visibility, a mix of alarms indicating obstacles approaching that were sometimes correct, and other times false alarms or missed alarms, and changing between autonomous and manual driving modes.

We used two buttons embedded in the steering wheel originally meant for shifting gears to serve two purposes -- first, when pressed at the same time, the car will switch from autonomous driving to manual or from manual to autonomous depending which mode the driver is already in. Second, when in autonomous driving mode, the driver can press the left button to decrease perceived trust level and press the right button to increase trust level on a scale of one to five. By default, the autonomous driving trust level was set to three, and when manually driving the trust level is set to zero because trust does not apply.

Our hypothesis was that human trust would be affected by various factors and decrease from the presence of missing and false alarms. We also hypothesized poor weather conditions would impact driver trust regardless of driving performance and that drivers would trust more when given the ability to switch to manual (semi-autonomous and not fully-autonomous).

III.   TESTING PROTOCOL

Part I. Pre-setup (Before arrival)
1. One hour before the participant's arrival, set up the equipment
    1. 1.Prepare experimental information table
        A. Add participant information in Sheet Content
        B. Duplicate Sheet Template and rename it as participant index (eg. S1)
        C. In participant sheet, right click Column Trial Index, click Randomize Range; Right click

Column Trial Index again, click sort range A->Z

1. 2. Scenario setup
   A. Open Prescan and invoke Matlab; All scenarios are in ScenariosNewDesign
   B. Set up the GoPro on the Tripod, recording the entire driving simulator
1. 3. Imotions setup
   A. GSR
      i. Check if Shimmer are charged, if not or unsure, charge it.
   B. Eye-tracker Glasses
      i. Charge batteries (Fully charged: 4.2 V)
      ii. Have wireless-adapter plugged into recording laptop
   C. Recording laptop
      i. Use Wi-Fi to connect wahoo
      ii. Use Wi-Fi 2 to connect Tobii
      iii. Check the IP address (in terminal type: ipconfig)!
      iv. See if the IP address is consistent with all the UDP blocks in Prescan Matlab simulink; if not, change the address in UDP blocks for all 16 scenarios.
      v. Run python script in Desktop/Trust Project/sendtoFD.py
1. 4. Verify that you have the following forms:
   A. Informed Consent forms (Papers, in the locked closet) and pen
   B. Experiment questionnaires (Use Ipad, safari, google drive, shared with me, Experimental materials, Experimental questionnaire, preview)
   C. Payment Form (Papers, in the locked closet)
2. Set up the greeting room

2. 1. Turn on all overhead lights
2. 2. Place a paper with "IN USE" near the lock on the lab door to prevent interruption

Part II Greeting (After arrival, before experiment)

1. Record the arrival time on the information table
2. Greet participant, provide them with the informed consent form, and explain it.

(Introduce yourself and hand consent form) *Thanks for coming out today. This form explains the details of the procedure of this experiment and the risks involved. It also describes the responsibilities and compensation of the participants in this experiment. We ask that you read through it, answer all of the questions, and sign at the end if you wish to participate in this study. As noted in the form, you are free to withdraw at anytime without penalty.*

3. Explain the experimental goal, procedure, and their responsibility

Today's experiment aims to study how participants trust this autonomous driving system. (Show them the driving simulator.) By trust, we mean the delegation of responsibility for actions to the automation and willingness to accept risk (possible harm) and uncertainty. You can use the tiny red buttons by the steering wheel to express your trust level on a scale of 1 to 5, with 5 means the highest trust. Left one for decrease and right one for increased trust level.

We are going to do 16 runs of experiments, each taking roughly 3 minutes.

Eight of them will be fully autonomous. This means the wheel, brake, and throttle will not respond to any input and the simulator will drive for you. The tiny red buttons, however, will be activated and allow you to express your trust level.

In the other eight runs, the system will begin driving autonomously as the default. You can switch between manual driving and autonomous driving modes by pressing the left and right red buttons simultaneously. When switching to manual mode, the trust level will drop and stay at 0. You cannot change your trust level in manual driving mode. And the trust level will be set to a default value 3 when switching back to autonomous driving mode. Please feel free to adjust the trust value based on your own feelings.

During the experiment, some incidents (such as pedestrians crossing the road) may occur and the autonomous driving system will try to handle them. The autonomous driving system will also try to send

an alarm when it detects an incident. There could be missing or false alarms.

4. If the participants decide to participate, have them fill out the pre-experiment questionnaire, check participant's driver license.

Part III Set-up equipment

1. Set up GSR Shimmer

GSR are recorded from the proximal phalanges of the index and middle fingers of the non-dominant hand using the Shimmer3 GSR+ unit. The sample rate is 128 Hz.

The two adjacent ports on the Shimmer will be connected to the index finger and middle finger. The third, separated port on the GSR will be connected to the ring finger;. Shimmer is attached with wrist straps.

    1) Configure GSR in Imotions
    2) Clean the skin where you intend to place the electrodes with an alcohol wipe
    3) Snap the GSR leads to disposable adhesive electrodes
    4) Place the recording electrodes onto the skin.
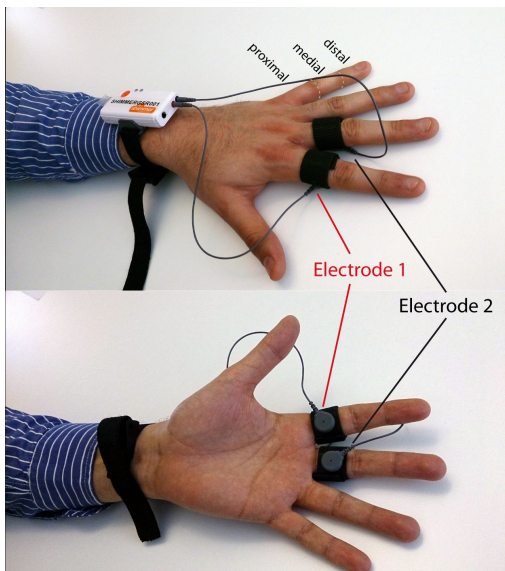   5) Connect the leads to the Shimmer sensor making sure to pair the electrodes to the correct channels.
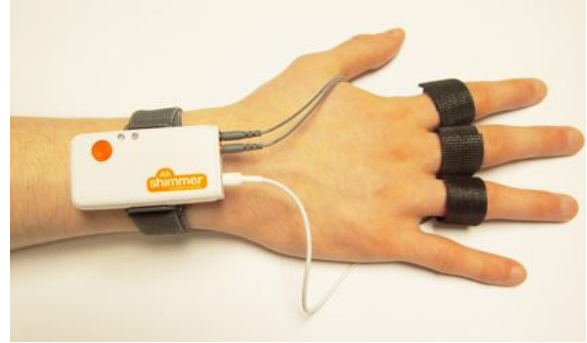

Fig 5. Shimmer EMG Setup

Fig 6. Shimmer GSR Setup

2. Set up Eye-tracker

Tobii Glasses 2 is used as the eye-tracker. The sample rate is 50 Hz.

On the lab laptop go to WiFi-2 and look for TG02B and connect. From there it will automatically connect to iMotions. Calibration using the card with a target it comes with will be required.

3. All data are synchronized through iMotions.

Part IV Start experiment

Imotions Project: Trust 2019

Prescan Scenarios: ScenariosNewDesign

    1. Make sure the python script is running. No need to close it during the whole experiment.
    2. Have Shimmer and Eye Tracker Connected. You should be able to see live values from GSR and heart rate.
    3. Keep track of the heart rate values. Adjust the ear clip position until have a continuous value between 60-130; (normally should around 75)
    4. Turn off the lights
    5. Run Baseline X (name it like S1_0_X): Ask the participant to sit in the simulator without running it. Record 3-minutes data in IMotion. (again, check heart rate)
    6. Run Baseline Y (name it like S1_0_Y) with participants in simulator check and make sure that GSR/heart rate are collecting data; check and make sure there is an incoming external event.
    7. Explain GUI to participants. Let them try change trust level, switch mode freely:

This is a 5-min baseline study in semi-autonomous mode. You will start with autonomous driving mode.

Now you can use the tiny buttons to change trust. (Let them change trust level). *As we are recording signals from your non-dominant hand, please try to keep its movements at a minimum and only use your dominant hand to change the trust level.*
And then you can switch to manual mode (Let them switch to manual mode and keep driving for 2 min). Please let us know if you feel anything emergent, otherwise please try not to talk to us when the experiment is running.
And then you can switch to autonomous driving if you are in the correct lanes. (Let them switch to auto).

Condutor 1	Conductor 2

1. Add a respondent for each run in iMotions. Use participant index_trial index_ trial ID as the name (eg. "S1_2_C", as Subject 1 is taking the 2nd run of experiment, and the scenario is C; "S1_0_Baseline" for baseline study); Select Gender
2. Click Rec in iMotions.
3. Re-calibrate the Tobii Glasses.
  1. Shine a flashlight or phone light directly on the black circle card to speed up calibration if you are having difficulty.
  2. Accept calibration in iMotion
  3. Press shift+space in iMotions to end trial.
  4. Take live marker (to be tested in pilot)
	1. In D:\ScenarioNewDesign\transition.m change the scenario name .
	2. Control +a to select all
	3. Press F9 to run simulation
	4. (If bug dialog comes up, Parse, Build, Regenerate)
	5. Make sure vehicle states pops up
	6. Use your own computer to takes notes on when and why trust changes on experimental table

Fig 7. Protocol for Two Conductor Trials

Part V After experiment
Use Shift+Space to end a study in iMotions.
1. Stop experiments;
2. Take off GSR shimmer, turn off and charge it;
3. Turn off Tobii Glasses, take the sd card and put it into IMotions laptop,
4. Right click project name Trust2019 in iMotions, click sync
5. Charge Tobii battery .
6. Turn off GoPro, export data to the desktop and charge it.
7. Have the participant complete the post-experiment questionnaire.
8. Have participants complete payment forms. Pay $20 gift card for the experiment. Ensure that previous participants' information is not visible.

IV. RESULTS

Using signal temporal logic (STL), we analyzed the data set containing results from the 19 participants, categorizing trials in the following way:
(1) Trials in which the participants stayed in autonomous driving mode and no event was detected for 30 seconds
(2) Trials in which participants changed trust level at least 15 seconds after an event
(3) Trials in which participants changed trust level at least 14 seconds before an event
(4-5) Trials in which participants encountered either early or late false alarms
(6-9) Trials in which participants changed the trust level in response to a false alarm
(11-12) Trials in which participants changed the trust level in response to a missing alarm

Overall, false alarms were more likely to cause trust to increase, with 25.2% of false alarms causing a decrease in trust and 18.5% of false alarms causing an increase in trust [2]. As for missing alarms, an event containing no alarm was 67.1% likely to cause a decrease in trust, while an event with an alarm was 51.3% likely to cause a decrease, representing a 15.8% net gain in the likelihood of a trust decrease when there is a missing alarm [2]. For trust increases, a missing alarm was 51.3% likely to cause an increase in trust, while an event with an activated alarm was 59.2% likely to cause an increase

in trust. All of these results show that both false and missing alarms have a relatively more negative effect on trust level than events where the alarms are operating properly [2].

V. Future Work and Further Research

Trust modeling is a significant concept in the prospective future of autonomous vehicles. Route planning is a ubiquitous service in our day-to-day lives; its most common purpose is to construct a route which minimizes *time spent* from point A to B. However, people are often willing to take a slower route to their destination if it feels significantly safer, i.e. they *trust* themselves to drive more successfully on it.

Trust is the key determinant in public adoption of self-driving vehicles. Our upcoming paper centers around the position that autonomous driving systems will need to be able to route to optimize user trust, unlike current routing software which only seeks to optimize time. In order to conduct this research, we had to first devise a novel route planning method for self-driving vehicles accounting for user trust. As evidenced by our prior research, trust is an observable and measurable state of mind. In order to route for trust, two things are critical to understand:

1) How trust evolves during a user's interaction with the self-driving vehicle
2) What decision (i.e. whether or not to switch from autonomous mode to manual mode) a user makes when facing incidents on the road

We used partially observable Markov decision processes (POMDPs) to construct virtual routes intended to maximize trust. POMDPs are a generalization of the Markov decision process, a discrete time stochastic control process used to model decision-making procedures [3]. It is important to note that experiments using routes constructed from POMDPs have already occurred---the analysis of the data collected, as well as work on the corresponding paper, is ongoing.

Before any trials were conducted, we collected a large amount of survey data using Amazon Mechanical Turk. Using this data, as well as data from prior experimentation, we developed both a trust dynamics model and a driver behavior model.

These models were used to construct the POMDP, from which we derived optimal route policy to design the course. The course was set up to maximize trust from point A to point B through a network of potential routes with different obstacles or incidents along the way. Between specific trials, experimental subjects were given scenario-specific questionnaires to report their level of trust of the simulator to handle incidents.

These survey data, as well as the sensory data collected in the trials, will be reproduced and analyzed in our upcoming paper, which is expected to release in 2020.

VI. Conclusion

This paper presents the design, procedure, and results of an experimental study of passenger trust in autonomous vehicles. While the results of the study implied a negative relationship between failures in the hazard detection of the vehicle and the passenger's trust in that vehicle, the fact that most of the volunteers participating in the study were college age adults with engineering backgrounds prevents the results of the study to be widely generalized. Additionally, the potential of physiological data to supplement the insights gained from reported trust was not fully explored in this study, and as such using physiological data more extensively is a natural route for further research on this subject. Overall, this experiment was a successful starting point for further inquiry into passenger reactions and trust in autonomous vehicles, the results of which could be instrumental for failure-proofing reliable self-driving systems in the future.

References

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