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Towards Leveraging the Driver's Mobile Device for an Intelligent, Sociable In-Car Robotic Assistant

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Abstract— **This paper presents AIDA (Affective Intelligent Driving Agent), a social robot that acts as a friendly, in-car companion. AIDA is designed to use the driver's mobile device as its face. The phone displays facial expressions and is the main computational unit to manage information presented to the driver. We conducted an experiment in which participants were placed in a mock in-car environment and completed driving tasks while stress-inducing phone and vehicle notifications occurred throughout the interaction. Users performed the task with the help of: 1) a smartphone, 2) the AIDA persona with the phone mounted on a static dock, or 3) the AIDA persona attached to a robot. Results revealed that AIDA users felt less stressed throughout the interaction, performed vehicle safety precautions more often, and felt more companionship with AIDA as compared to smartphone users. Further, participants developed a deeper bond with AIDA as a social robot compared to AIDA as a static, expressive agent.**

I. INTRODUCTION

Given the significant amount of time people spend behind the wheel of their vehicles, there is an increasing demand for enjoyable in-vehicle experiences that do not compromise passenger safety. Increased travel times also make it more difficult for the driver to focus solely on operating the vehicle while trying to ignore other activities. Frequently, drivers tend to multi-task in an attempt to make better use of their time (e.g. Checking traffic conditions, monitoring the vehicle, and exchanging calls and text messages). As a result, many drivers manipulate their In-Vehicle Infotainment (IVI) systems or mobile devices while they drive.

Interacting with such devices while driving results in high cognitive load and increased stress for the driver. Unfortunately, these dangerous behaviors can amplify the driver's lack of focus and can lead to accidents. For example, in 2011, The United States Department of Transportation reported that ~420,000 people were injured in motor vehicle crashes involving a distracted driver [1].

While several IVI systems have been designed to keep the driving experience as safe as possible, it is still inconvenient for drivers to limit themselves to the systems that are part of the automobile. Many users would like to access their favorite applications (apps) everywhere, particularly inside their cars, despite the fact that some of these apps were not designed for a driving context. A device that requires less driver manipulation and has access to the driver's favorite services could reinforce safety and reduce mental overload, thus making the driving experience safer and more efficient.

In addition to safety, social and emotional factors play a vital role in the driving experience, yet many IVI systems neglect these influences. For instance, drivers typically treat their cars with more care than other devices in their lives, e.g. many drivers name their vehicle, which suggests an inherent driver-car bond [2]. Also, car manufacturers do consider social factors of their driver demographic, like personality and emotion, as key aspects of car design [3]. Further, the driver's emotional state can have a great impact on behavior and safety. Tired, stressed drivers are less likely to fully focus on the road, as compared to alert drivers. Angry, frustrated drivers are more prone to road rage, since they may make more risky decisions that could potentially lead to accidents.

Despite the appreciation of social and affective factors in car design, flashing icons and chiming sounds are traditional modes of driver-vehicle communication. The driver can sometimes be annoyed by these alerts, which hinders the driver-car bond. A social IVI system may present a new mode of driver-car communication by leveraging interpersonal influences, thus strengthening this bond and making the driving experience more enjoyable.

II. MOTIVATION

Drivers use mobile devices both inside and outside of the car. Advances in smartphone technology have made it easier for functionalities like email, calendar, music, web search, etc. to be accessible to the user everywhere. Because these devices contain personal information about the user, and can access to a wide variety of information via the Internet, leveraging this information can be a powerful tool in making the intersection between a person's driving experience and everyday life more adaptive, contextually aware, and personalized. Coupling personalized data with existing phone apps and services could make the driving experience more seamless and satisfying for the driver. Moreover, a system that not only manages all of this information, but also preemptively initiates actions given certain circumstances could make driving more efficient.

III. RELATED WORK

A. *Prioritizing Information*

The AIDE (Adaptive Integrated Driver Vehicle Interface) system [4] collects information about the vehicle and its surroundings, i.e. data related to navigation, collision

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warnings, the Internet, entertainment systems and messaging services. An information management unit then performs a priority analysis and determines the most relevant information to deliver to the driver at the most appropriate time. The system communicates with the user in an organized way that reduces stress and cognitive overload.

In [5], driver distraction was addressed differently than that of the AIDE approach. Instead of delaying notifications, the information was presented upon arrival, and additional cues were included to express the priority level of the message. These cues would allow the driver to decide when to deal with the received message. They found that these informative interruption cues were learned quickly and identified accurately to reduce cognitive load.

While these projects share common goals with our work, we also want to explore the social aspect of driving and the possibility of taking proactive actions that reach out to other applications to offer more support to the driver.

B. *Affective and Speech Interfaces*

Nass and Brave concluded that matching driver emotions with the IVI system's tone of voice improved overall in-car performance [6]. Matching happy drivers with an enthused voice and upset drivers with a subdued voice resulted in superior driving performance as compared to oppositely matched pairs. Also, much work has been done regarding speech interfaces for driver-car communication [7, 8].

While these works reveal the benefits of affective and speech-based interfaces, they do not explore how short-term speech interactions can be monitored to develop deeper personalization with the driver over time. Additionally, systems capable of delivering information in an expressive, sociable way could also improve the quality of driver-car communication. If the vehicle can express itself in a way that feels natural and familiar to the driver, then there could be a deeper understanding of the messages conveyed by the car.

C. *In-Car Accessibility of Mobile Devices*

Technologies like Bluetooth headsets and docking stations on windshields and dashboards allow drivers to access their mobile devices without compromising safety [9]. In [10], a system was designed that integrates the IVI system and the user's smartphone. Mobile devices run all phone services, while the IVI system is responsible for input/output functions to handle a wider range of applications.

While these systems are convenient, they degrade the user experience because they are highly reactive. The driver still has to initiate many actions to obtain necessary information.

D. *Robotic Assistants*

Fig. 1 shows BYD's Qin [11], Nissan's PIVO [12], and Pioneer's Carnaby [13]. These robots handle services like wireless internet networks, music, driver fatigue detection, navigation, etc. all while socially interacting with the driver. However, these systems decouple functionality and social interaction, whereas we aim to integrate these facets into a seamless architecture. Further, neither of these systems leverage the driver's smartphone for added assistance.

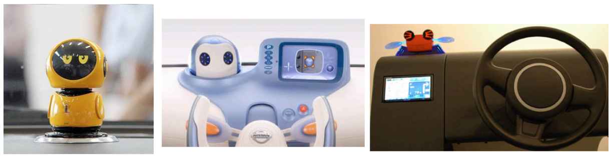


Figure 1. BYD's Qin (left), Nissan's PIVO (middle), Pioneer's Carnaby (right).

Figure 2. In-car concept of AIDA.

IV. CORE CONTRIBUTION

With motivations from the previous sections in mind, we have developed an Affective Intelligent Driving Agent (AIDA) [14], a socially expressive robot that acts as a friendly, in-car assistant, Figure 2. AIDA uses the driver's smartphone as its face, thus promoting in-car safety by keeping the phone out of the driver's hands. Using app-based functionality, AIDA displays facial expressions and manages and delivers vital information about the phone, the vehicle, and the city environment to the driver. Because AIDA leverages the driver's personal device, AIDA integrates existing phone functionality with aspects of the driver's daily life for deeper personalization. Further, AIDA is a proactive agent capable of initiating task-specific phone actions for more fluid driving interactions that are less distracting or stressful to the driver. We evaluated our platform with a user study where AIDA was shown to better assist people and promote greater sociability as compared to traditional smartphones during mock driving tasks.

V. SYSTEM FRAMEWORK

The system consists of a robot, an Android smartphone and an external computer (CPU). The smartphone is the main computational unit and runs an AIDA app, which communicates between the driver, the car, the robot, other phone apps, and outside information sources. For now, the

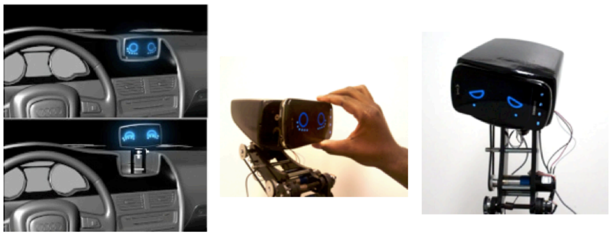


Figure 3. AIDA recessed into the dashboard (top-left), AIDA extended (bottom-left), smartphone snapping into AIDA's head shell (middle), AIDA expressing sadness via facial expressions and body movement (right).

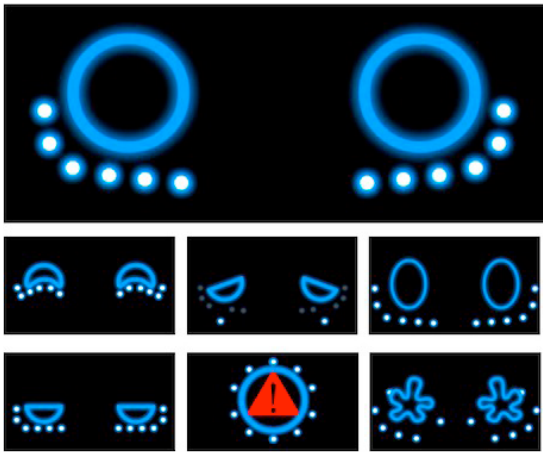


Figure 4. AIDA’s range of expressiveness: idle, happy, sad, surprised, bored, warning, disoriented (top to bottom, left to right).

CPU serves as a phone-robot communication portal.

A. *Hardware*

The AIDA robot consists of a 5 degree-of-freedom head and neck mechanism. Fig. 3 (left) illustrates that the robot is meant to sit seamlessly in the dashboard in the relaxed position as not to distract the driver, but conveys stronger non-verbal cues in extended positions. Because of its range of motion, AIDA is capable of direct eye contact with the driver and other passengers for deeper social interaction.

We use an Android-powered, Samsung Epic Galaxy S smartphone as the face of the robot. The robot’s head shell was designed so that the user can easily snap in the phone, Figure 3 (middle). The phone displays animation-based facial expressions and iconic messages like warning signs, Figure 4. These expressions are matched with physical movements to improve AIDA’s expressive capabilities. For example, Figure 3 (right) shows AIDA expressing sadness via the crying face animation in conjunction with a sunken head pose.

B. *Communication Pipeline*

Fig. 5 shows AIDA’s internal system architecture. AIDA’s implementation makes use of our R1D1 codebase, a java-based cognitive architecture for designing synthetic brains for virtual and physical creatures [15]. AIDA leverages two versions of R1D1 for full functionality, a condensed, app-based version running on the phone and another version running on the CPU. The CPU acts as a communication portal between the phone and the physical robot. Motor commands from the R1D1 phone app are sent to the robot via Internet Relay Chat Protocol (IRCP), Figure 5 (right). We require that the phone and CPU be connected to the same wireless Internet network during operation.

The Android phone is the core of AIDA’s framework, which manages internal apps and sensor data, as well as communicates with the physical robot, Figure 5 (middle). We developed an AIDA app, which encapsulates this functionality, displays facial expressions, and interconnects other apps. The AIDA app also queries external sources like the Internet for further assistance. The driver communicates with the device via speech commands and to a lesser extent, through tactile interactions, Figure 5 (left).

C. *Smartphone Apps*

AIDA leverages several apps to become more versatile in its functionality and personality.

1) ***User-Specific Apps****:* These apps are either included in the phone’s internal application suite or purchased through the Google Play Store (Android Market).

ipconfig – Finds the IP address of the wireless network.

Calendar – Uses Google calendar to manage the driver’s appointments and allows the driver to create new events.

Contacts – Stores acquaintances’ contact information.

Messaging – Allows the users to send and receive text messages to others. Text can be input through voice commands, the virtual keyboard, or the physical keyboard.

2) ***AIDA-Specific Apps****:* Excluding the LTTS Susan app, we developed these applications with specific AIDA-related functionality in mind.

LTTS Susan – A text-to-speech engine used to convert

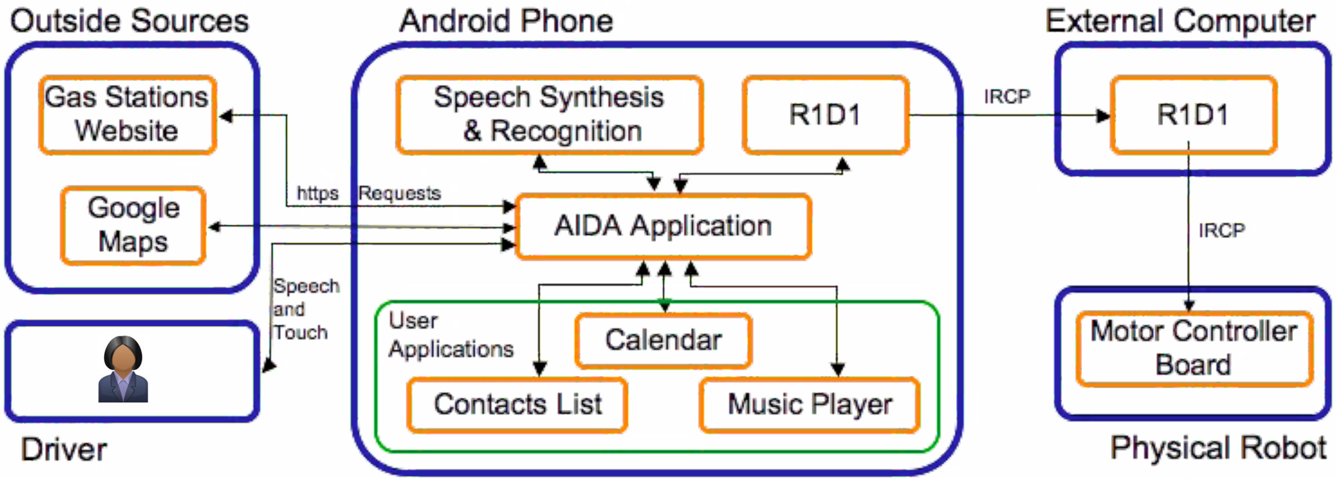


Figure 5. AIDA’s communication pipeline.

written text to verbal utterances using a female voice. This app is used to verbalize emoticons and text statements that the driver may receive during the driving task.

Gas Station Finder (GSF) – Finds nearest gas stations given the driver's current location. Upon launching, this app shows a list of local gas stations to choose from. Once the driver selects a station, the app navigates them to this destination.

Travel Time Calculator (TTC) – Determines how long it will take for the driver to navigate to a certain location. The driver inputs an address and the app determines their travel time given the driver's current GPS coordinates.

AIDA – As part of its core functionality, this app integrates all driving-specific apps into a seamless architecture, while an expressive face acts as the main interface. The driver interacts with this app via speech and to a lesser extent, through touch.

R1D1 – A communication hub between the phone, robot, and CPU that controls the interaction. It sends motor positions to the robot given commands from the AIDA app.

VI. EVALUATION

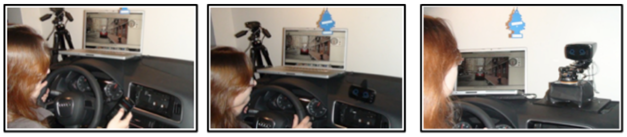
Our experiment seeks to investigate peoples' attitudes towards AIDA and to compare user interactions with AIDA versus mobile devices during mock driving tasks. For now, we are not assessing AIDA's impact on driver car handling (e.g. steering, response time, etc.). Instead, we will evaluate AIDA's ability to provide a more seamless way for the driver to handle the data flow between themselves, the car, and the outside world while promoting sociability.

A. Experimental Conditions

Three conditions were used for experimentation, Figure 6. In the **PHONE** condition, Figure 6 (left), users completed the task with the aid of the smartphone equipped with apps. Similar to the way people currently use their cell phones in their cars, participants used the Calendar, Contacts, Messaging, GSF, and TTC apps to assist them.

In the **AGENT** condition, Figure 6 (middle), users completed the task with the aid of the AIDA app with the phone mounted on a static docking station. This idea is similar to existing IVIs and in-car docking stations.

In the **ROBOT** condition, Figure 6 (right), users completed the task with the aid of the AIDA app with the phone attached to the robot. This explores a new driver-vehicle interface, which is a hybrid of driving-specific functionality and social expressiveness.



Case PHONE Case AGENT Case ROBOT

Figure 6. Three experimental conditions.

B. Protocol

Upon arrival, participants were given an orientation, which explained the procedures of the experiment. We demonstrated how to use the smartphone, the phone apps, and how to input text using voice commands, the physical keyboard, and the soft keyboard. Participants were allowed to practice with the phone until they felt comfortable using it for the experiment. Users were then placed in a mock in-car environment where they were videotaped. A mock driving scene [16] was displayed on a laptop screen that was placed on top of a dashboard rig. In the ROBOT condition, we programmed the robot to move only when the car was static in the videos to minimize distractions to the driver.

Users had two events to attend while stress-inducing phone alerts and vehicle warnings occurred throughout the 15-minute interaction. We instructed users to act as naturally as possible and to perform any in-car actions (i.e., signaling, lane switching, accelerating, braking, etc.) that they would normally do in a real-world driving task. Thus, users had the choice to make/answer phone calls or to send/read text messages. When participants reached their final destination, they were prompted to exit the environment. They then answered a questionnaire regarding the interaction.

C. Experimental Environment

Fig. 7 shows the experimental environment. It features the dashboard on top of a small table, Figure 7-a, and the laptop that displays the mock driving scene, Figure 7-c. It also includes rear and side-view mirrors, Figure 7-d, for the driver to see images behind them, Figure 7-h. Before each experimental trial, we intentionally adjusted the mirrors so that the rear images were slightly out of focus. Our goal was to give the driver a visual cue to adjust the mirrors without explicit instruction. The interaction was videotaped using front and back view video cameras, Figure 7-e. The environment also featured a chair with a two-point lap seatbelt, Figure 7-f. We did not inform participants of this seatbelt. Instead, we adorned the seatbelt with decorative tape to give the driver a visual cue to fasten their seatbelt without explicit instruction. A videogame foot pedal controller was used to simulate accelerator and break pedals, Figure 7-g. If participants needed assistance during the interaction, they could press a nearby help button, Figure 7-i.

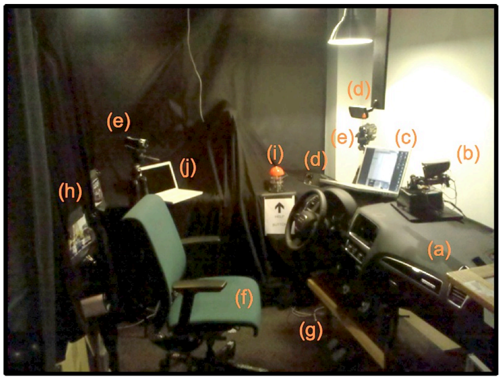
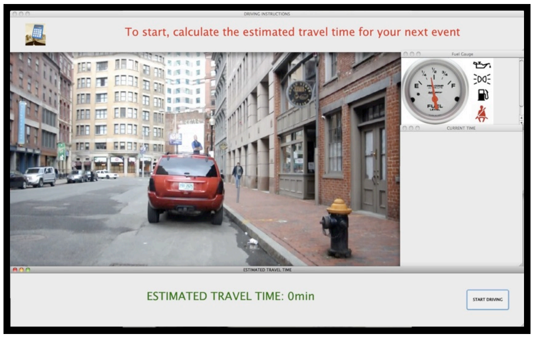


Figure 7. Experimental environment (ROBOT set-up).



To start, calculate the estimated travel time for your next event

ESTIMATED TRAVEL TIME: 0min

Figure 8. Laptop screen interface with instructions (top), the driving scene (middle), vehicle conditions (upper right), and estimated travel time for the next event (bottom).

A second laptop, Figure 7-j, was used so that we could remotely watch the interaction via Skype. We could see if the participant pressed the help button as well as send text messages and phone calls to the user at appropriate times. With Skype, we could see and hear everything in the environment, but participants could not see nor hear us.

D. *Experimental Task*

1) Events: Two events were pre-programmed into the smartphone's Google calendar, 1) Lunch with the user's fictitious friend named Jaylen and 2) Salsa dance lessons. We also included event locations and contact information.

2) *Starting the Interaction*: In the PHONE condition, when participants entered the environment, they were told to watch the laptop screen for starting instructions. Fig. 8 shows a screenshot of the simulator screen for starting the interaction. In general, the interface displayed instructions (top), the driving scene (middle), vehicle conditions (upper right), and the estimated travel time for the next event (bottom). Our hope was for users to fasten their seatbelt and adjust their mirrors before starting. To alert the user, they saw the seatbelt image turn red on the screen and heard an audio tone, similar to alerts that drivers experience in a real car. Users then needed to calculate their estimated travel time for the first event in order to activate the driving scene. To do this in the PHONE condition, users had to launch the Calendar app to figure out the address, keep a mental note of this data, then launch the TTC app and input the address. Once the TTC app determined the travel time, the R1D1 app (launched before the participant entered the environment) commanded the driving scene to activate automatically.

In AGENT and ROBOT (the AIDA cases), users saw the same prompt on the screen, and additionally, AIDA gave a friendly greeting and explicitly urged users to fasten their seatbelt and adjust their mirrors. With this alert, we explored AIDA's influence on enforcing driver safety. AIDA also asked the user if their next event is a "Lunch with Jaylen." Once the user replied, "Yes," AIDA then automatically calculated the estimated travel time and the driving scene activated on the laptop screen.

3) *Traffic Warning*: Five minutes into the interaction, traffic causes the user to become late for their first event. In the PHONE condition, users saw a prompt on the laptop screen and heard the same audio tone as mentioned before. At this time, we called the user's phone, pretending to be Jaylen, to find out why they were late. This alert was intended to induce cognitive load and to test the driver's multi-tasking skills under pressure. The user had complete autonomy over their phone actions in response to this alert.

In the AIDA cases, users saw the same screen prompt and heard the same audio alert. Additionally, AIDA calculated the user's new travel time and preemptively asked them if they would like to send a text to Jaylen, i.e. us, letting him know that they are running late. Upon receiving the user's text, we replied with a text message that said, "No worries, I am running late myself." Upon receiving this text, AIDA asked the user if they would like to hear the incoming text message from Jaylen, and AIDA read it aloud.

4) Transitioning Between Events: In PHONE, once the user arrived at their first destination they saw a prompt on the simulator screen and heard the audio alert. They were then instructed to wait while the driving scene reset itself. In the AIDA cases, users received the same alerts and AIDA congratulated them on successfully making it to the first event. They were then instructed to wait while the driving scene reset itself. To navigate to the second event, all users repeated the actions in Part 2).

5) *Oil Warning*: Upon navigating to the second event, users received a low oil warning. In PHONE, users saw a screen prompt, heard the audio alert, and the oilcan image turned red. This prompt instructed users to schedule an oil change appointment with the Calendar app once the interaction ended. Our goal was to investigate the users memory skills under stressful situations.

In the AIDA cases, users received the same alerts. However, AIDA also expressed sadness because the vehicle was low on oil. AIDA began to cry, as seen through facial expressions and audio tones in AGENT, and even stronger, through body movement in ROBOT, Figure 3 (right). AIDA then prompted users to schedule an oil change once the interaction ended. We wanted to know if AIDA's sadness had an affective impact on the driver, consequently causing them to remember to schedule the oil change.

6) *Fuel Warning*: Five minutes later, participants received a low gas warning. In PHONE, users saw the screen's gas gauge change to "E," i.e. empty, the gas icon turned red, and they heard the audio tone. Participants could do nothing or use the GSF app to find a gas station. If the user chose to get gas, then they were navigated to a fake gas station in the video to fill up their tank. If users did nothing, then they did not stop and proceeded to their final destination. This warning tested the user's decision-making skills under stress by provoking them to consider if there was enough gas in the car to make it to the final event.

In the AIDA cases, similar alerts occurred and AIDA asked the user if they wanted to get gas. Given their command, the user then proceeded to the gas station or their final destination as discussed previously.

7) Ending the Interaction: Once users made it to their final event, the interaction was complete. In PHONE, users received an audio alert and saw a screen prompt instructing them to exit the environment. In AGENT and ROBOT, users received the same alerts plus AIDA gave them a friendly farewell. This behavior was intended to gauge the user's emotional state after the interaction. All users should have scheduled an oil change with the Calendar app upon exiting.

VII. HYPOTHESES

Taking insights from various works in anthropomorphic interface technology, we predict five hypotheses. Healey, Dabek and Picard ascertained that affective interfaces played a key role in reducing user stress [17]. Applying this knowledge to the context of our driving task, we predict:

H1 – Mental Overload: AGENT and ROBOT users will find the task less mentally demanding and easier to perform than PHONE users.

Nass, Steuer and Tauber showed that interfaces with human representations were influential in modifying human behaviors [18]. Exploiting this information for reinforcing safe driving habits, we predict:

H2 – Safety Precautions: AGENT and ROBOT users will be more likely to fasten their seatbelt and adjust their mirrors than PHONE users.

H3 - Distraction: AGENT and ROBOT users will stay focused and keep their eyes on the road (i.e. the laptop screen) more often than PHONE users.

Kidd and Breazeal revealed that users experienced a deeper sense of sociability with a robotic assistant as compared to an affective agent [19]. Considering this work in the context of our driving task, we predict:

H4 - Sociability: ROBOT users will feel more likeability and social awareness from AIDA than AGENT users.

Medina revealed that people more easily retrieve memories that are tied to strong emotions [20]. Relating this work to our memory task during the experiment, we predict:

H5 – Emotion on Memory: ROBOT users will be more emotionally affected by AIDA than AGENT users. Thus, ROBOT users will remember to schedule an oil change after the interaction more than PHONE or AGENT users.

Gustafsson, et al. claimed that the aesthetic of mock environments must be immersive enough to compel users to perform actions that they would normally do in real-world environments [21]. Thus, we predict:

H6 – Environment Authenticity: All PHONE, AGENT and ROBOT users will experience a sensation of reality and perform realistic actions in the mock environment.

VIII. DEPENDENT MEASURES

Behavioral probes were used to measure stress, cognitive load, memory, and agent sociability. This was done throughout the experiment via vehicle and phone alerts, AIDA notifications and the task of scheduling an oil change. Each hypothesis was evaluated through a combination of questionnaire responses and video footage data.

Survey questions from accepted sources provided us with standard methods to assess sociability [22], engagement and affect [23], cognitive load [24], and environment authenticity [21]. We also asked self-defined questions to evaluate measures like the appeal of the robot's form factor.

Video analysis was used to measure user attention, mood, and adherence to safety. We coded for eye gaze, facial expressions, gestures, utterances and in-car actions. We define positive affect as smiles, laughs, excitement and positive utterances and gestures expressed by participants. Conversely, we define negative affect as frowns, confusion, anger, sadness and negative utterances and gestures.

IX. RESULTS

A total of 44 participants (13 PHONE, 17 AGENT, and 14 ROBOT) were recruited from the Cambridge, Massachusetts area. There were 20 males, 24 females, and the mean age was 28.6 years.

Video footage was transcribed by two objective individuals for behaviors discussed in Section VIII. Krippendorff's alpha (α) criterion was used to determine inter-coder reliability where α-values between 0.8 and 1 (inclusive) suggest acceptable consistency. We found α = 0.873 for key behaviors highlighted in Tables I and II. Cochran's Q test (CQT) was used to assess variance among all conditions. Pair-wise comparisons were then found using continuity-corrected McNemar's tests with Bonferroni correction (MT). The MT pair-wise comparisons are made between PHONE-AGENT (Φ_{PA}), PHONE-ROBOT (Φ_{PR}), and AGENT-ROBOT (Φ_{AR}), Table I.

Questionnaire replies were scored on a 5-point Likert Scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree. Mean (M) and Standard Deviation (σ) values of user responses were calculated for each experimental condition, Figure 9. ANOVA F-values (AFV) were calculated to assess global variance among all conditions. Pair-wise comparisons were then found using the

TABLE I. OBSERVATIONS FROM VIDEO DATA WITH MT COMPARISONS

	PHONE	**AGENT**	**ROBOT**	Φ_{PA}	Φ_{PR}	Φ_{AR}
a) Fastening seatbelt	15.38 %	76.47 %	71.42 %	9.63	7.26	0.26
b) Adjusting mirrors	7.69 %	82.35 %	92.86 %	14.7	17.93	0.001
c) Scheduling an oil change	38.46 %	47.06 %	7.14 %	0.033	2.96	3.87

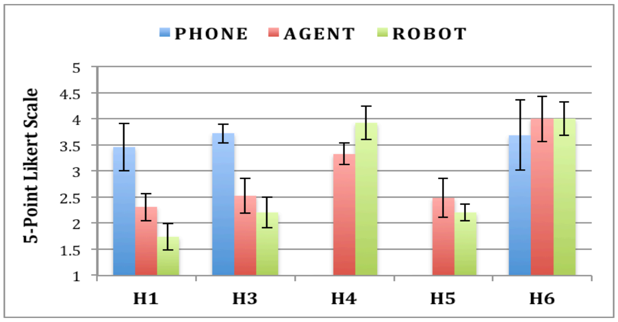


Figure 9. Mean (*M*) and Standard Deviation (σ) values of questionnaire responses (error = ± σ).

TABLE II. OBSERVATIONS FROM VIDEO DATA WITH TKM COMPARISONS

	PHONE	**AGENT**	**ROBOT**	**T_{PA}**	**T_{PR}**	**T_{AR}**
a) Mean start time	154.92 sec	61.47 sec	62.57 sec	93.45	92.35	1.1
b) Mean time eyes were off the road	46.38 sec	30.24 sec	24.79 sec	16.14	21.59	5.45
c) Total positive affect	7.0	13.5	16.5	6.5	9.5	3.0
d) Total negative affect	5.5	2.0	1.5	3.5	4	0.5

Tukey-Kramer Method (TKM). TKM comparisons were made between PHONE-AGENT (T_{PA}), PHONE-ROBOT (T_{PR}) and AGENT-ROBOT (T_{AR}), Table II.

A. *Hypothesis 1: Mental Overload*

Fig. 9 (H1) shows the average replies to questions regarding high cognitive load during the task. AFV revealed that PHONE users generally felt that the task was stressful, fast-paced, and mentally demanding while AGENT and ROBOT users largely disagreed ($F(2,41) = 3.88$, $p = 0.029$). TKM comparisons showed a significant difference between each pair-wise group (T(40,3), all $p < 0.05$).

Table II (a) shows that PHONE users also took longer to begin the task than AIDA users. TKM comparisons, T(40,3), showed significant differences between PHONE-AGENT and PHONE-ROBOT, but not between AGENT-ROBOT.

Table II (d) illustrates that PHONE users expressed more negative affect throughout the task and sometimes gave utterances like, “I have no idea what to do,” even though they received a thorough orientation, viewed pictures of the laptop interface, and practiced with the phone before-hand. TKM comparisons, T(40,3), showed significant differences between PHONE-AGENT and PHONE-ROBOT, but not between AGENT-ROBOT.

B. *Hypothesis 2: Safety Precautions*

Table I (a-b) highlights observations regarding in-car safety. As indicted by questionnaire responses, most users were at least aware of the mirrors and seatbelt in the environment. Yet, PHONE users did not take the necessary safety precautions as often as AGENT or ROBOT users. With CQT, we found a significant difference among all conditions for seatbelt fastening ($\chi^2(2) = 22.42$, $p < 0.001$) and mirror adjustments ($\chi^2(2) = 20$, $p < 0.001$). MT comparisons ($\Phi(2)$, $p < 0.05$) further revealed significant differences between PHONE-AGENT and PHONE-ROBOT, but not between AGENT-ROBOT.

C. *Hypothesis 3: Distraction*

Table II (b) illustrates that PHONE users had their eyes off the road, i.e. the laptop screen, much more than AIDA users ($F(2,41) = 4.88$, $p = 0.023$), (T(40,3), all $p < 0.05$). Fig. 9 (H3) indicates that PHONE users felt more distracted than AIDA users ($F(2,41) = 4.38$, $p = 0.019$). TKM comparisons, T(40,3), showed significant differences between all pair-wise groups.

D. *Hypothesis 4: Sociability*

Table II (c) shows that AIDA users expressed more positive affect as compared to PHONE users ($F(2,41) = 4.92$, $p = 0.039$). TKM comparisons, T(40,3), showed significant differences between all pair-wise groups. Further, in an AGENT-ROBOT comparison, Figure 9 (H4) shows that ROBOT users felt more likeability and social awareness with the AIDA robot than AGENT users with the static display ($F(1,29) = 5.89$, $p = 0.003$).

E. *Hypothesis 5: Emotion on Memory*

We wanted to know if users were more likely to remember to schedule an oil change at the end of the interaction because they were emotionally affected by AIDA becoming sad. Table I (c) shows percentage of users who did remember the oil change. With CQT, we found a significant difference among all conditions ($\chi^2(2) = 6.17$, $p < 0.05$). MT comparisons ($\Phi(2)$, $p < 0.05$) revealed a significant difference between PHONE-ROBOT and AGENT-ROBOT, but not between PHONE-AGENT.

Fig. 9 (H5) shows that users did not feel sympathetic towards AIDA’s sadness in either condition ($F(1,29) = 3.77$, $p = 0.401$). Most AGENT and ROBOT users found AIDA’s sad emotional state, particularly the crying, to be absurd or comical. Video footage revealed that many users reacted by smirking, laughing, or making shocked expressions, yet one ROBOT user did express sympathy.

F. *Hypothesis 6: Environment Authenticity*

Fig. 9 (H6) shows that all users felt that they experienced a sensation of reality in the mock in-car environment during the experiment ($F(2,41) = 0.38$, $p = 0.68$).

X. DISCUSSION

Results presented above provide evidence that AIDA has the potential to better assist motorists during driving tasks than smartphones alone. They also suggest that AIDA as a social robot can promote sociability and influence drivers better than AIDA as a static-mounted expressive agent.

H1: Mental Overload – Validated. Since AIDA users did not fumble with phone as much and AIDA performed preemptive actions to assist users, AGENT and ROBOT users found the task to be easier than PHONE users.

H2: Safety Precautions – Validated. Due to AIDA's ability to persuade more users through its social presence, AGENT and ROBOT users fastened their seatbelt and adjusted their mirrors much more than PHONE users.

H3: Distraction – Validated. PHONE users were overall more distracted than AIDA users because they had to manipulate the phone more. Even when some PHONE users tried to send texts while driving, their messages were written in broken English, e.g. "I'mm runnknv lTe." AIDA users effortlessly gave voice commands and immediately brought their gaze back to the screen. Some users even commanded AIDA without looking away from the screen.

H4: Sociability – Validated. The AIDA robot was able to make more direct eye contact and elicit more personally directed non-verbal cues to the driver as compared the static AIDA agent. Thus, ROBOT users felt a stronger social bond with AIDA. Some ROBOT users even had friendly dialogue with AIDA and waved goodbye to the robot as they left the environment. These behaviors were not seen in AGENT.

H5: Emotion on Memory - Not Validated. ROBOT users did not schedule the oil change more than AGENT users. While all users were emotionally affected by AIDA's sadness, many were not empathetic and felt that the crying was too extreme for the situation. This highlights that the design of AIDA's behaviors need to be believable to the context. Future investigation will explore appropriate social cues for AIDA to elicit to better suit driving circumstances.

H6: Environment Authenticity – Validated. All users experienced a sensation of reality in the mock environment.

XI. CONCLUSION

Overall, the idea of introducing a pro-active, social robot into the driving context shows potential. Harnessing the users cellphone, with personalized information and access to other apps and services, is a promising approach to explore long-term driver-vehicle interactions. An in-and-out-of-car system could be highly versatile and contextually aware of the driver and the environment. For example, with access to city events, restaurant reviews, locations of points of interest, etc., AIDA could foster a more seamless and personalized driving experience. One could envision how this could also make car-specific information and alerts more user-accessible rather than requiring drivers to read user manuals to decipher alerts and flashing lights. It is also intriguing to consider how a sociable IVI system may be able to subtly persuade people to become safer drivers over time, or to keep the car better maintained. Ultimately, we wish to deploy the system in vehicles to investigate how AIDA improves the driving experience and develops deep personalization to the driver over time.

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