AUDI Sociable Car Project Report
Year One

Mikey Siegel
Dr. Cynthia Breazeal
MIT Media Lab

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Abstract

The Personal Robots Group (PRG) at the Massachusetts Institute of Technology (MIT) Media Laboratory has partnered with Audi to create the Sociable Car Project, as part of the Sociable Car Senseable City (SC^2) Project. We aim to expand the relationship between the car and the driver with the goal of making the driving experience more effective, safer, and more enjoyable. As part of this expanded relationship, we plan to introduce a new channel of communication between automobile and driver/passengers. This channel would be modeled on fundamental aspects of human social interaction including the ability to express and perceive affective/emotional state and key social behaviors. In pursuit of these aims we have developed the Affective Intelligent Driving Agent (AIDA), a novel in-car interface capable of communicating with the car's occupants using both physical movement and a high resolution display. This interface is a research platform, which can be used as a tool for evaluating various topics in the area of social human-automobile interaction. Ultimately, the research conducted using the AIDA platform should lead to the development of new kinds of automobile interfaces, and an evolution in the relationship between car and driver. The following document summarizes the work leading up to the development of AIDA, technical details of the AIDA platform, as well as a proposed research agenda for the Sociable Car Project.

Contents

Chapter 1

Introduction

The Personal Robots Group (PRG) at the Massachusetts Institute of Technology (MIT) Media Laboratory, along with the Senseable Cities Group from MIT's Department of Architecture has partnered with Audi to create the Sociable Car Senseable City (SC^2) project. This document describes PRG's contribution, referred to as the *Sociable Car Project*, which includes development of the area of social human-automobile interaction, as well as the creation of a novel interface for associated research. The following chapter describes the context and motivation for the Sociable Car Project and the development of the Affective Intelligent Driving Agent (AIDA) research platform.

1.1 Context and Motivation

Imagine a car that knows you, and responds to your social and emotional context. A car that acts like a friend or driving partner, rather than simply a tool for transportation. This car can open up a new world of possibility for communication. By expanding the space of communication you redefine what value the car can offer. Information can be provided to the driver with a heightened context awareness, increasing its relevance. Bond between human and vehicle can be strengthened, increasing both enjoyment of the driving experience and commitment to the Audi brand. Behaviors beneficial to driver and environment can be encouraged, making the car a safer, more effective environment. The goal of the Personal Robots Group in the Sociable Car Project is the manifestation of these ideas through the development of AIDA, a novel in-car interface, and an associated research agenda.

Building upon many years of applying an understanding of human social interaction to human-robot interaction (HRI) and human-computer interaction (HCI), we are working to endow cars with a new array of expression and perception capabilities. Combined with an intelligent system for processing this data, we hope to create a new channel of communication within the automobile. By expanding the communicative capabilities of the car, we hope to also greatly expand both the breadth and depth of the relationship between human and car. This shift in communication and understanding between human and car is expected to lead directly to a deeper driver-car bond, greater enjoyment of the driving experience, and a new-found ability to provide the driver with information based on the driver's social and emotional context. Ultimately, we hope to be able to use this new channel of communication to influence the driver in a way that benefits them, their environment and other connected entities.

In the pursuit of these aims the Personal Robots Group has worked over the last year to develop an in-car system called the Affective Intelligent Driving Agent (AIDA). This system is designed to be capable of a broad range of interactive modalities, including the expression and perception of human-like emotion. AIDA takes the form of a sophisticated mechanical system, situated in the dash, capable of both expressive physical motion, and high-resolution graphical display. The entire mechanism is carefully designed to seat seamlessly into the dash, capable of hiding its capacity for physical movement while keeping its display visible.

AIDA is designed as a research platform, rather than a commercial prototype destined for mass production. It likely boasts a greater capacity for movement and expression then would be required in a commercial application, but it is specifically that surplus which makes it an ideal research tool. The area of social human-automobile interaction is in many ways a new research topic, and AIDA is a new type of interface. The exploration of various interaction modalities, and the ability to ask a wide variety of research questions, is fundamental to this project, and directly facilitated by the versatile AIDA platform.

This research, which is planned for the second and third year of the collaboration, will gauge the effectiveness of the AIDA system. Specifically, we hope to explore AIDAs ability to influence the beliefs and behavior of the driver, which will directly leverage the system's unique ability to form meaningful relationships. This capacity to change behavior can be applied to a wide range of in-car applications. Examples include encouraging more environmentally friendly driving, discouraging dangerous behavior such as text message use, and even reinforcing safe driving behavior. It is believed that this research direction is uniquely enabled by the systems physical form and expressive ability.

The prevailing paradigm for communication within automobiles is function based and mechanical - unable to interact with the driver on a personal or social level. An example is the way in which cars deal with the need for drivers and passengers to buckle their seatbelts. Although the need for seatbelts is undebatable some people, for various reasons, continue to resist buckling up. Almost exclusively, reluctant drivers and passengers are dealt with by exposing them to a repetitive sound specifically designed to be irritating. The strategy, which is a form of coercion, essentially forces compliance as the only escape from the noise.

Just as it would be in human interaction this type of communication is hurtful and insulting, fostering resentment in the driver and ultimately damaging the human-automobile relationship. An alternate approach would leverage the new channel of communication proposed by the Sociable Car Project. Instead of coercing the driver with an irritating sound, it might be possible for a specially designed interface to actually show concern for the driver's safety by expressing fear or anxiety. These feelings would be displayed not through text or a standardized symbol, but through a physically co-located agent capable of communicating using movement and facial expressions. This type of communition is understandable on a fundamental and intuitive level, speaking to the driver in a social language typically inaccessible by automobile interfaces.

Leveraging this new type of communication, the expression of fear or anxiety might motivate the driver out of empathy or personal concern. Not only would this have the effect of compliance with the buckle request, but the car's concern for the driver's safety would strengthen their bond. This is in direct contrast to the results of the typical in-car communication. Variations on this communication strategy are used throughout the car, from low gas alerts, to the beeping signaling that a car door is ajar. Applications for the AIDA system (discussed in Section 4.2) include restructuring these existing forms of communication as well as the pursuit of previously infeasible interaction models.

1.2 Contents

The main body of this report is divided as follows:

Chapter 2 will explore the work leading up to the development of the AIDA platform including detailed discussion of various early proposals. Following that, Chapter 3 will be an explanation of the current system as it exists including the rationale behind certain design decisions and some technical documentation. Finally, Chapter 4 will propose a timeline for the next two years of the project and detail a proposed research direction.

Chapter 2

Initial Designs

The development of the AIDA system was preceded by a number of early concepts and designs. This chapter provides an overview of the general methodology that went into those designs. Following the overview, Section 2.2 will provide a description of some early concepts leading ultimately to the AIDA system (described in Chapter 3).

2.1 Development of the AIDA System

The development of the existing AIDA system was preceded by a number of concepts all with the same goal: Creating a research platform capable of social expression/perception in order to push the boundaries of human-automobile interaction. One quality that varied throughout these concepts was their physical means of communication. These variations were present in their quality of movement, physical form, and potential for emotional expression.

One design challenge, present in each concept and typically a distinguishing factor among them, was the way in which they integrated into the car. The reason why such emphasis was placed on this consideration was because of a related question: How unified should the interface seem to be with the car itself? This continuum of unification has the interface as the face or essence of the car at one end and as an entity completely distinct from the car at the other (e.g. your dog in the backseat). It is believed that both the systems physical design, and the way it is unified into the automobile will define how it is perceived within the car at large. There were a number of primary questions that stemmed from this decision, namely: What features in particular would push the interface to one side of the continuum or the other? And, at what end of the continuum should the interface sit at?

Arguments have been made for the merits of placing the system at various points along the continuum. Structuring it as totally separate and autonomous from the vehicle might grant it the ability to act as a distinct partner in driving, thus giving it the ability to make third party comments about the car, its features, behavior, and other aspects. This separation might grant it certain favor in situations where judgment on the car was made. A disadvantage of this design decision might be that it wouldn't be considered credible in conveying the emotional state of the car, or other information pertaining to details of the cars internal mechanical/electrical state. It also might foster a potentially confusing dualism between interface and automobile.

An interface designed to be the face or essence of the car might be better positioned to foster a bond between car and driver. If the communication directed from this system to the car's occupants was perceived to be emanating from the car itself, then those statements might have more direct impact. Generally speaking, efforts were made to place the system closer to this end of the continuum in order to maximize the potential bond between car and occupants.

2.2 Early Concepts

The following section shows some of the key concepts leading to the design of the AIDA system. The first concept in Section 2.2.1 shows some examples of actuated, explicitly anthropomorphic interfaces. Section 2.2.2 steps away from specifically human expression and uses a more abstract expressiveness. In Section 2.2.3, the stretch concept uses the dash itself as a flexible dynamic display. Finally, Section 2.2.4 shows the concept directly preceding the current AIDA design.

2.2.1 Explicit Anthropomorphism

The earliest concepts, depicted in Figures 2.1 and 2.2, focused on a very explicit form of anthropomorphism. These were attempts to take existing means of physical and emotional expression and fuse them with the car's interior. In these cases, less focus was placed on the technical feasibility of the ideas. Rather, there was an effort to explore the ways in which human-like expression might be transplanted into the car's interior.

The expressive eye concept (Figure 2.1) attempted to leverage Audi's existing design theme of equal sized speedometer and tachometer behind the steering wheel. These images show an extreme example of the idea where

Figure 2.1: Eye concept showing actuated eyes merged with the existing speedometer and tachometer. Other designed used LCD screens in place of the actuated gauges.

the dash material around the gauges is actuated and able to move like a flexible skin. This flexibility would allow for very explicit, even cartoon-like expressiveness.

More toned down and technically feasible branches of this concept used LCD screens in place of the speedometer and tachometer, and abandoned the flexible skin. In this variation the screen could be made to show animated eyes when appropriated, but could instantly be made to show the technical information normally provided by the gauges.

This concept was favored because of its somewhat straightforward conceptual integration into the existing car interior. The gauges, two ever-present components of the automobile, and distinct features of Audi's interior aesthetic, became a conduit for expression.

The mouth concept (Figure 2.2) followed a similar aesthetic of using actuated flexible skin in order to mimic organic structure and motion. The Audi symbol above the mouth suggests eyes, though these were not necessarily expressive. A mouth is a primary source of expressiveness in the human face and thus would be a reasonable choice as output for a socially expressive interface. This concept does not fit into the existing logic of the Audi interior in the way that the eyes do.

2.2.2 Abstract Displays

The following concepts (Figures 2.3, 2.4 and 2.5) are less literally anthropomorphic in their means of expression. The concept shown in Figures 2.3 and

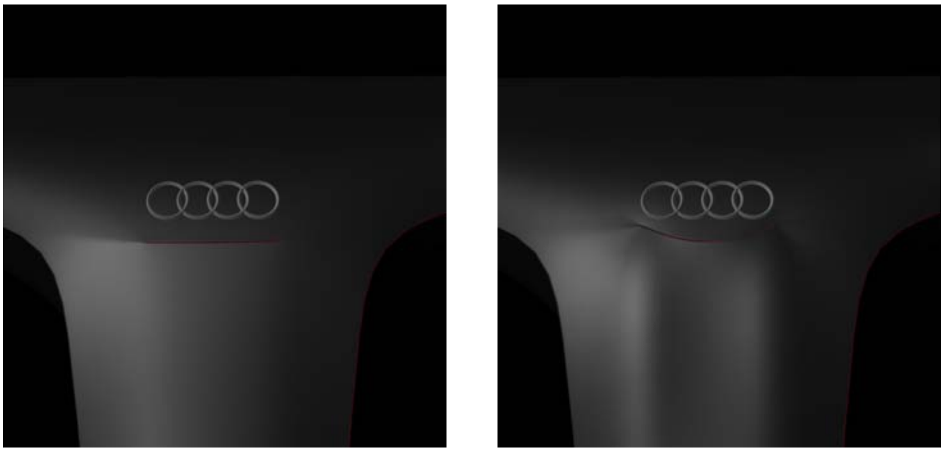

Figure 2.2: Mouth concept showing actuated mouth/lips above the central console. They Audi logo is meant to be suggestive of eyes.

2.4 attempt to blend with existing design elements by using the Audi logo itself as an expressive interface. The logo is both actuated, and equipped with a high resolution display granting it a wide range of expressive abilities.

Figure 2.3: In this concept the Audi logo is used as a means of expression. These images show some examples of the proposed range of movement.

Figure 2.5 focused less on physical movement, and more on tactile interaction. It was imagined to be an advanced multi-touch display possibly using Frustrated Total Internal Reflection (FTIR) technology combined with a projector embedded in the dash. Though technically possible, there was no intention to use any kind of human-like expression with this concept, rather, we intended to explore more abstract forms of expression. Similar to HAL in 2001 a Space Odyssey, it was imagined that even a simple point of light or shifting pattern could serve as an expressive means of communication.

In these concepts the expressiveness comes less from a literal parallel to human expression, but rather leverages people's tendency to project anthropomorphic qualities on ordinary objects. This human tendency to anthropomorphize is heavily leveraged throughout animation, from early Disney

Figure 2.4: In this concept the Audi logo is used as a means of expression. The images show the proposed display capabilities.

shorts, to modern 3D full length features. Using these techniques it is possible to turn something like an orb or an Audi logo into an engaging character with believable agency, and a capacity for feelings and empathy.

2.2.3 Stretch Concept

The stretch concept depicted in Figures 2.6 and 2.7 was an effort to physically merge the interface with the car in a totally seamless way. We attempted to accomplish this by imagining a dash constructed of a flexible membrane. This membrane, when not active, would suggest nothing unusual. When desirable, the dash could *come to life*, subtly changing shape, even turning to *face* the driver or passenger(s). A projector hidden below the dash could back-project upon the membrane turning the deformable fabric into a living dynamic display.

This concept was thought to be a novel way of fusing an expressive interface with the interior of the car itself. Subtle when needed, suggestively anthropomorphic, and seeming to be representative of the car itself, this concept was high on the list of candidates. It was ultimately abandoned because it was thought to be too novel and not intuitively understandable as a social communicator. Because the initial prototype is meant to be used as a research tool, we sought to avoid extremely novel interfaces because the impact of that novelty on the driver could not be directly accounted for.

2.2.4 Preliminary AIDA Designs

The concept depicted in Figure 2.8 was an early idea leading directly to the design of the AIDA system described in Chapter 3. These images abstract away the mechanical system, and focus on the idea of a robotic head that is able to completely embed itself into the dash. This example uses an array

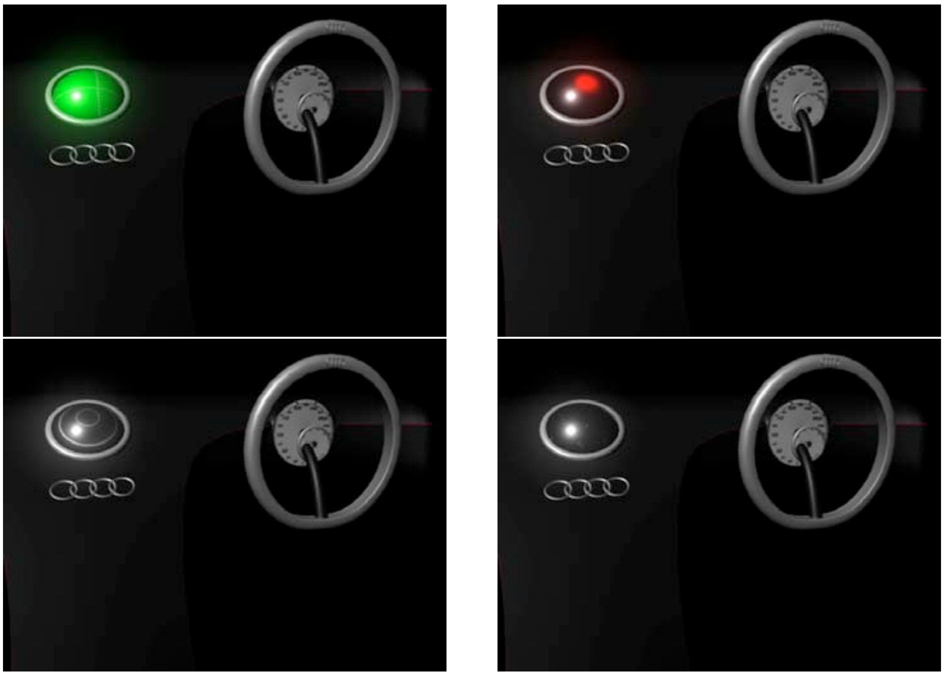

Figure 2.5: The orb depicted in these images is designed to be both a high resolution display, and a multi-touch surface. Though technically possible, there was no intention to depict explicitly anthropomorphic features on the surface. The focus in this concept was on a more abstract and simple means of expression.

of LEDs as a display, though this was later abandoned in favor of the high-resolution projector.

Unlike the stretch concept discussed in Section 2.2.3, the robotic head concept was thought to be more explicitly robotic. This obvious adherence to a certain robotic archetype was thought to produce fewer unaccounted for responses due to some inherent novelty of the system.

2.3 Summary

This section presented the underlying motivations behind the early concepts leading ultimately to the AIDA system. These concepts ranged in anthropomorphism physical movement, and the way in which they integrated into the existing design concepts of the car. The Explicit Anthropomorphism concepts (Section 2.2.1) included actuated eyes, and a mouth, and drew very explicitly from human expression. Section 2.2.2 discussed more abstract concepts that relied less on human expression, and more from concepts in an-

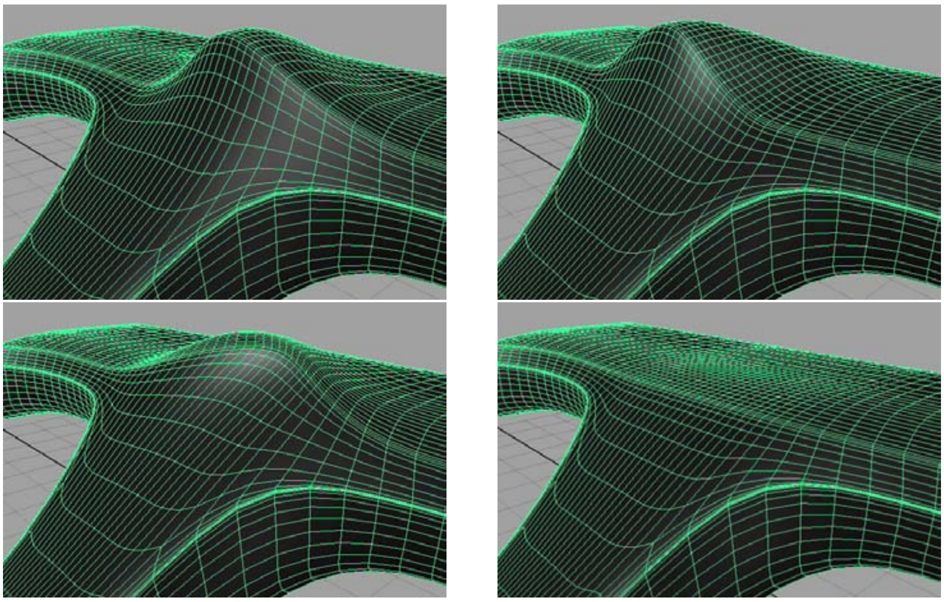

Figure 2.6: Stretch concept showing dashboard made of flexible membrane. A projector embedded below the dash turns the membrane into a dynamic, actuated display. Grid lines illustrated the nature of the proposed motion.

imation and illustration. The stretch concept (Section 2.2.3) showed some elements of the abstract expressiveness present in the concepts from Section 2.2.2, but integrated into the car as an actuated deformable dashboard. Finally, Section 2.2.4 shows the actuated robotic head concept leading directly to the present AIDA concept.

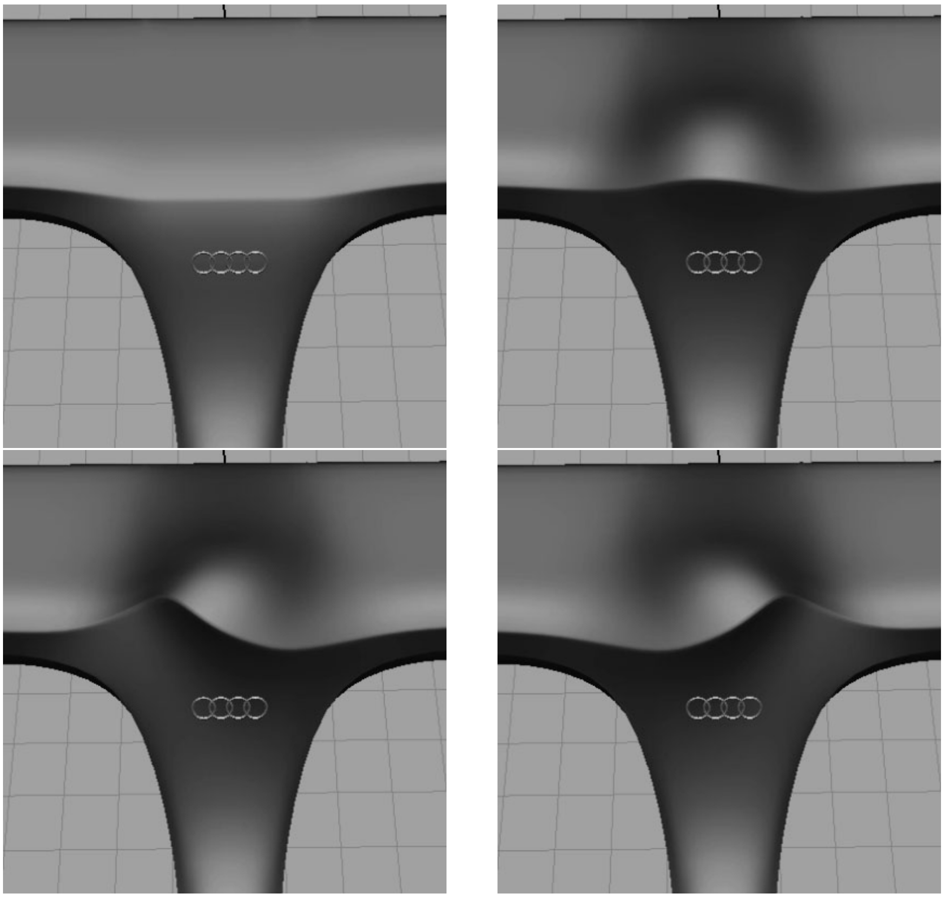

Figure 2.7: Stretch concept showing dashboard made of flexible membrane. A projector embedded below the dash turns the membrane into a dynamic, actuated display. Grid lines illustrated the nature of the proposed motion.

Figure 2.8: Later concept leading directly to the design of the present AIDA system.

Chapter 3

AIDA: Affective Intelligent Driving Agent

The AIDA system is a physical interface meant to act as a platform for researching social human-car interaction. It consists of a mechanical head/neck mechanism along with a head shell. The head shell boasts an embedded projector, and the entire system is designed to sit seamlessly into the dash when not in use. Details of the system are provided below in Section 3.1.

Certain dangers may also be present with this type of socially interactive system. The driver may be drawn to the anthropomorphic movement and expression. This same type of expression though, may prove to increase the ease with which information is conveyed. These concepts are discussed in detail in Section 3.4.

3.1 System Overview

The AIDA system consists of a five degree of freedom (DOF) robotic head/neck mechanism topped with a plastic 3D-printed head shell (see Figures 3.1 and 3.2). Embedded inside of the head shell is a laser projector allowing the front of the shell to act as a high resolution display. The head itself is designed to be seamlessly embedded into the dash when not in use such that the front would always be visible and capable of acting as a display (see Figure 3.3).

The capacity for expressive movement coupled with the ability to seamlessly embed into the dash was thought to give the system the ability to adapt to a wide range of situations. All intermediate positions, from fully embedded to completely emerged, should have the capacity for meaningful expression.

Once implemented, system must be context aware, only moving when

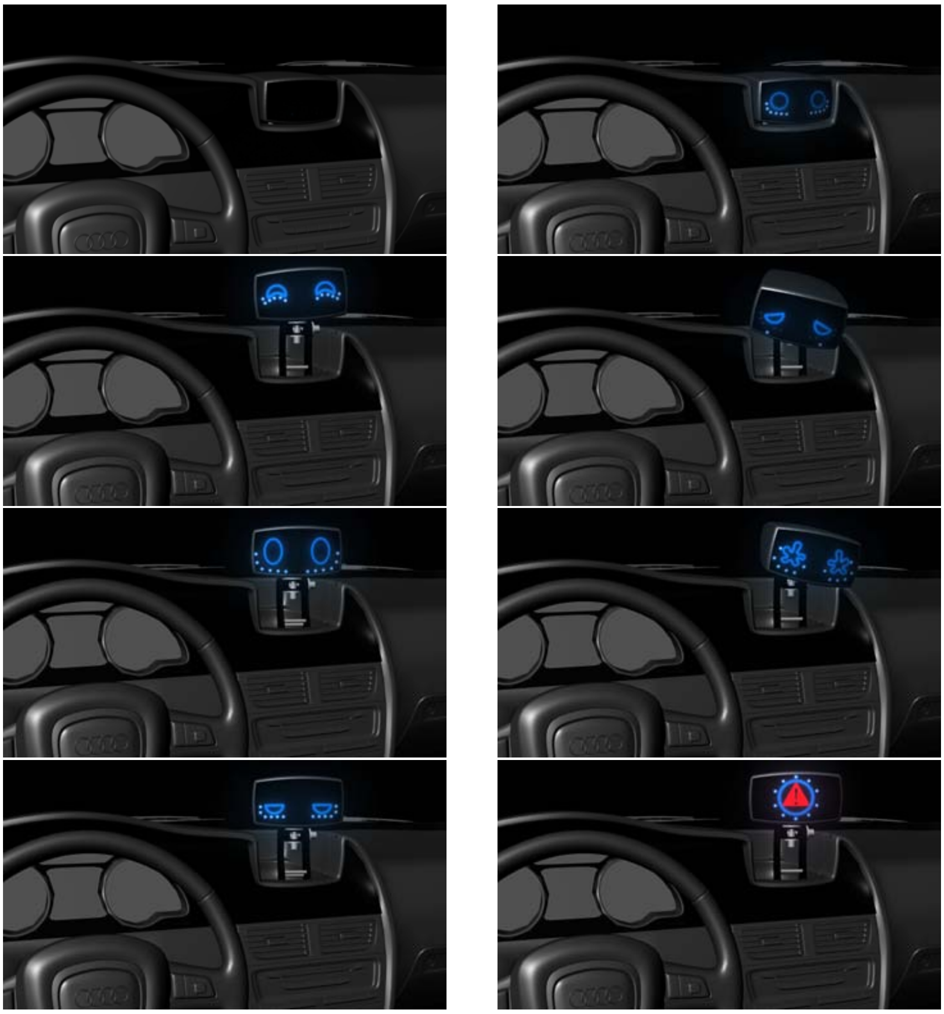

Figure 3.1: Current AIDA concept rendered in a 3D environment with a variety of facial expression and poses.

appropriate. We believe that movement may only be necessary at key events in the driving experience, such as when the driver is entering or leaving the vehicle. The knowledge that the system is capable of expressive movement might be enough to build up a certain social credibility with the driver and passengers. This social credibility is carried by the interface, even when it is fully embedded in the dash, allowing it to have a much greater impact than a completely static display, even when it is itself static.

The system as currently configured has a small subset of the ultimate range of inputs and outputs imagined for the final design. The primary output is the laser projector embedded in the dash. One of the major engineering challenges in the design of the system was the placement of this projector.

Figure 3.2: The current AIDA implementation with fully functional mechanical systems and embedded prjector.

It required a two mirror reflection system, and a complex 3D ray tracing model which accounted for the mirror positions, projector position, physical constraints of the inner head shell, and the position of the front projector surface (see Figure 3.5).

The chosen projector, built by Microvision, is an early manufacturer sample of an advanced form of projection technology which rasters RGB laser light onto the projection surface using an array of MEMs mirrors. A particular advantage of this device over conventional optical technology is that the image is consistently in focus, even across the curved surface of the shell face. Though it might have been less of an engineering challenge to simply place an LCD screen at the face of the device, it was a firmly held belief that the embedded projector created a unique and seamless look and feel not found in other in-car interfaces. Actually, because of the unique access to this technology, it is probable that this is among the first uses of an embedded micro projector as the display of an actuated robotic system.

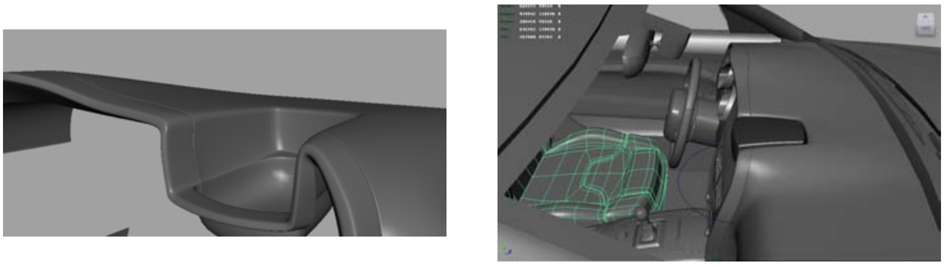

Figure 3.3: Figures showing details of the AIDA dash integration including the cavity into which AIDA would recess (left) and the head shell fully recessed into the dash (right).

An array of capacitive sensors, along with accompanying electronics and computer interface, is under development in collaboration with the Audi ERL. The sensors will give AIDA the ability to detect human touch on different regions of the head shell (see Figure 3.4). Eventually, with accompanying software, different touch styles can be classified based on sensor information. For example, a pat, as different from a stroke, as different from push might be uniquely identified and responded to appropriately.

Figure 3.4: Figures showing an AIDA head shell responding to integrated capacitive touch sensing (left) and the internal electronics (right).

Because AIDA is necessarily tethered to a computer (currently an Apple *Mac Mini*), it also has the sensing and output abilities of a personal computer. These include microphone (sound input), speaker (sound output), and, of course, any peripheral attached to the computer. Currently, AIDA does not use any sound input or output though this will surely be an added and necessary feature once the primary behavioral and learning software begins development.

A video camera connected to the computer via USB was used for the current working prototype as a way of detecting faces. The camera was positioned at the base of the system, and gave AIDA the ability to detect not only the presence of human faces (as unique from background objects) but also their rough position in space. With this information AIDA was able to convincingly look towards faces, and respond appropriately to the presence of new faces or their extended absence.

A later version of the system will be fully integrated into a test vehicle. At that point AIDA should have direct access to the vast array of vehicle information available via the CAN bus, such as speed, seat occupancy and proximity to other vehicles. During the earlier research phase of the project this information will be provided by the driving simulator.

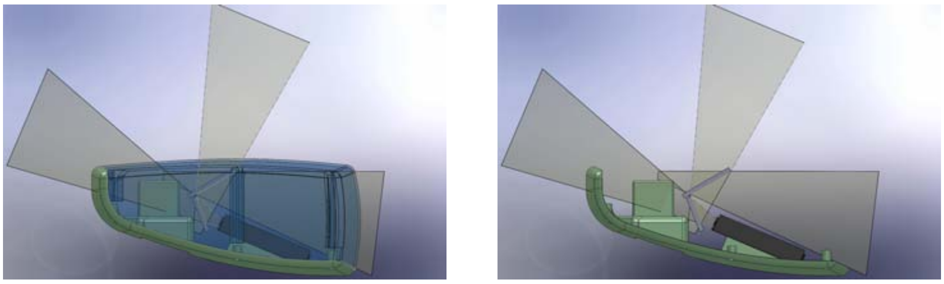

Figure 3.5: Raytrace of two mirror projection system with (left) and without (right) top of head shell in place. The triangles represent the path of the lasers coming from the projector.

3.2 Software Implementation

The software currently controlling AIDA was built upon a substantial architecture, designed originally for the control of synthetic characters, and later adapted for use with robots. The architecture allows for the rapid development of very sophisticated behaviors and artificial intelligence. Though a simple demo has been developed for the AIDA system, the focus until now has been the design and development of the physical system and theoretical aims of the project.

The current demo incorporates basic sensing capabilities provided by a video camera in order to create a dynamic response to changes in the immediate environment. Using the camera mounted at its base, AIDA is able to recognize faces in its immediate environment. By making some assumptions about distance, AIDA is then able to look towards the faces it sees and make eye contact. Upon seeing a new face, AIDA shows an expression of excitement, and upon not seeing a face for some time AIDA looks bored. The expressions are accomplished through a combination of physical movement, and facial expressions projected onto the front of the head shell.

As currently implemented, the software is meant as a placeholder capable of demonstrating the expressive range of the system. As Chapter 4 discusses, future work will focus on the development of sophisticated behavior capable of responding to various environmental conditions using a wide range of sensors.

3.3 Design Considerations

AIDA was designed such that it would fit seamlessly into the dash when recessed. There was also some effort to make the shell as smooth and featureless as possible in order to accentuate the novel capabilities of the embedded projector. And of course, there was some effort to make the head shell suggestive of a head without the use of any explicit facial features. The goal was an explicitly robotic look that might match the sleek interior of the Audi.

The eyes went through a number of iterations but ultimately settled at the design seen in Figures 3.1 and 3.2. This styling was directly inspired by the headlight style seen on certain modern Audi models. The dots are used as a sort of upside down eyebrow, and double as tears during the crying expression.

Though there certainly were some design considerations, much more work can be done to improve the appearance of the system. It would be helpful if designers from Audi were able to make some contribution to the styling of future versions. Though a number of next generation concepts have been sketched (see Figure 3.6) there remains space for further development.

3.4 Safety Considerations

A number of existing streams of communication presently exist in modern automobiles, including the standard beeps and blinks of the dash, Navigation systems, car stereos, and cell phone conversations. It is important to assess the risk of the proposed type of social interface, as compared to those traditionally present in the automobile.

It is clear that the anthropomorphic nature of an interface such as AIDA make it especially suited to attracting human attention. While we have discussed the advantages of such capabilities, we have not addressed the

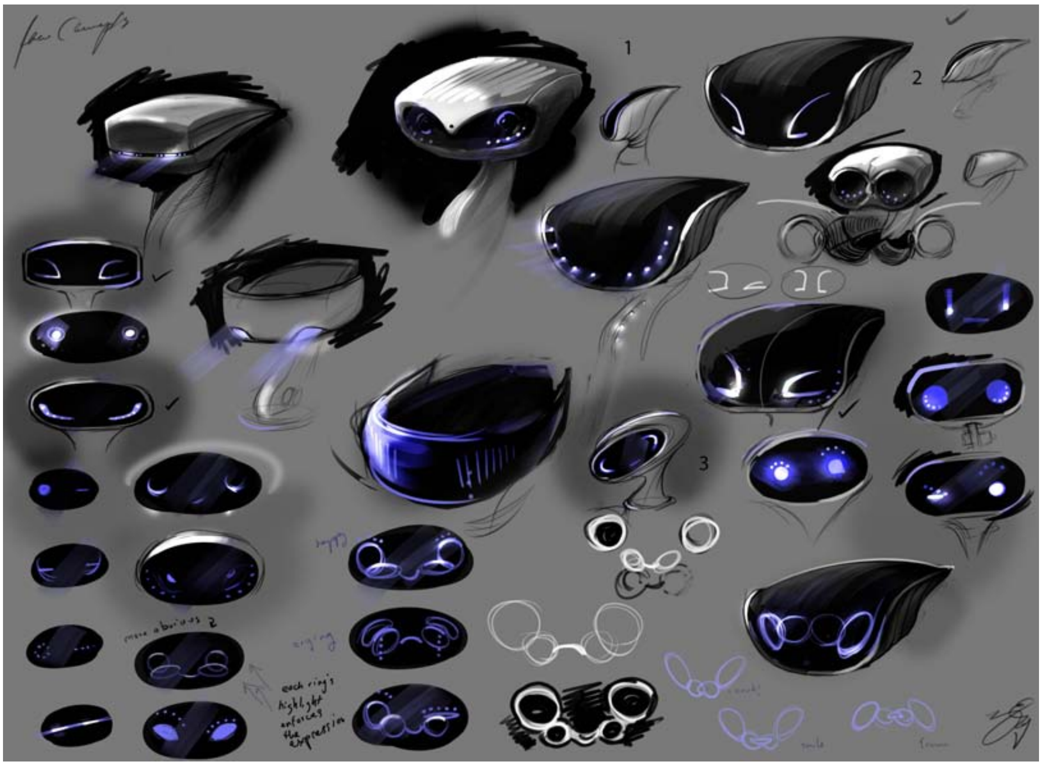

Figure 3.6: A variety of design concepts for the AIDA eyes and head shape. Art by Fardad Faridi.

potential negative impact on the driving experience. One possible negative consequence of such a system is the distraction it might cause the driver. It is possible that because it has features that humans are especially tuned to notice, such as eyes and expressive movements, it might be more distracting than a navigation interface, or even a phone conversation.

In contrast, a passenger is not considered to be more distracting than a phone call, and definitely not more distracting than a text message. Oddly this is in contrast to what one might imagine to be an increased distraction caused by the more engaging qualities of a human in the passenger seat. A physically collocated person is very close to the driver, moves without warning and tends to talk to the driver freely.

Perhaps the reason why the passenger is less distracting is because it is a fundamentally natural and intuitive interface. Humans have evolved to communicate in a very specific way, and will strive to do so even in the face of an entirely non-anthropomorphic display. It is possible that the absence of certain cues or interactive components from some in-car systems violate some primitive expectation, distracting the driver more than a physically collocated human.

Another possible source of the distraction discrepancy could be the passenger's unique ability to respond quickly to the driving context. This includes an awareness and ability to act on the driver's affective state, and the road conditions.

It might be possible that a social interface, incorporating many aspects of human communication might in some ways be less distracting to the driver under certain conditions than many traditional forms of in-car communication. This might especially be true when the information being conveyed by the car to the driver is of an unusually complex or otherwise challenging nature. Under normal circumstances the means for conveying potentially disturbing or irritating information to the driver has no consideration for the driver's social, emotional or driving context. An intelligent, social interface could dynamically change its behavior in order to convey information in the way most suited to that particular driver's needs at that particular time

3.5 Summary

AIDA was developed as a research platform for exploring new types of in-car communication. It was designed with the ability to physically and graphically interact in a social context. Its ability to physically move is thought to grant it a certain degree of social credibility, even when completely embedded into the dash to minimize distraction. Though the system does pose a potential risk as a novel interface, its ability to communicate in ways that are naturally and intuitively understandable might, in some cases, make it safer than other traditional means of communication.

Chapter 4

Future Work

Future work on the AIDA system will include refinement of the electro-mechanical systems, development of sophisticated control software, design and execution of user studies, and eventually the design and testing of a second version of the device. These challenges will be addressed in the order in which they appear on the projected timeline. Following the timeline, Section 4.2 will elaborate on the proposed research agenda including ideas for practical applications.

4.1 Timeline

Date Achieved	Milestone Description
1/04/2010	Design of user study
5/15/2010	Development of sensing and software system to enable user testing
5/15/2010	Development of driving simulation environment
9/01/2010	Execution of user study
1/01/2011	Redesign of AIDA based on user study results
2/01/2011	Integration of AIDA V.2 into test vehicle
5/15/2011	In-vehicle testing of AIDA V.2

Table 4.1: Timeline showing milestones and their planned completion date for the next two years.

4.1.1 Design of User Study

The aim of the user study will be the validation of the design and underlying concepts of the AIDA platform. This research stands to answer a number of questions relating the validity and importance of social human-car interfaces. Also, questions regarding physical movement within the car will also be addressed. The proposed research direction focuses on behavior change as a far reaching topic with numerous applications. Aspects of this research direction are made uniquely accessible with the introduction of an emotionally expressive in-car system. Details of the proposed study and applications for behavior change research are provided in Section 4.2.

4.1.2 Development of Sensing and Software System to Enable User Testing

A number of additional systems will need to be developed in order to bring the AIDA system up to the technical level needed to run user testing. Much of this will be dependent on the details of the study and to what degree the robot's behavior will be pre-scripted. In the case of pre-scripted behavior, a puppeteering interface would need to be developed capable of monitoring and controlling the robot's behavior in predefined ways. This would need to be built upon a number of more primitive autonomous actions such as face detection and look-at, basic emotion detection, touch sensing, etc. In either case the study would need a suite of technology for detecting and recording subject behavior. This would include both video and audio recording that could be used for later analysis or reference.

4.1.3 Development of Driving Simulation Environment

The driving simulation environment will be designed and built in collaboration with the Audi ERL, and will ultimately reside at the MIT Media Laboratory. It should consist of some physical components of an automobile interior including a dashboard, pedals, shifter, appropriate seat, and other relevant items. These physical components should be fully functional within the driving environment, for example, the gas pedal should act to accelerate the simulated automobile. Two separate dashes will be necessary: one completely unmodified, and the other with AIDA fully integrated as defined by the supplied 3D renderings. The former will be used as a control condition for the study. The AIDA-dash integration along with the unmodified dash should be supplied by Audi.

In addition to the physical components of the simulator, a large projection screen, projector, and computer to run the simulator will be required. The simulator setup should be located in a confined space with minimal distraction, with the projection screen positioned such as to occupy much of the driver's field of view when facing forward. The simulation software should be provided by Audi. Also, Audi should assist in integrating the physical components of the simulator (steering wheel, pedals, shifter, etc.) into the simulation software environment.

4.1.4 Execution of User Study

The user study will take place at the Media Lab using the previously established simulation environment. Over the course of approximately four months, human subjects will be recruited by the MIT Audi fellow for the purpose of participating in the user study. All aspects of the study will need to be approved in advance by COUHES, the MIT Internal Review Board.

4.1.5 Redesign of AIDA Based on User Study Results

The results of the user study should lead to insight with regard to the design of the AIDA system. This insight will be applied to the redesign of the physical interface, as well as the software system. These changes should be optimized to best suit a predefined set of functional goals for the system. Also, Audi should work with MIT to incorporate automotive engineering principles in the new design in order to make the interface suitable for integration into a fully functional automobile. This automobile integration will be a major technical challenge and will need to be executed in close partnership between Audi and MIT.

4.1.6 Integration of AIDA V.2 Into Test Vehicle

The modified AIDA system will ultimately need to be integrated into a fully functional automobile. This integration should be done under the supervision of Audi ERL and will likely require in depth knowledge of various electrical and mechanical systems present in the car. This integration will, of course, also require the use of a car by MIT provided by Audi.

4.1.7 In-Vehicle Testing of AIDA V.2

Once AIDA has been integrated into a functioning test vehicle a new round of testing will be required. These tests will verify the hypothesis upon which the changes from AIDA V.1 to V.2 were based. Depending on the details of the modifications made, and the final form of the modified system, it might be possible to perform a similar study to that performed with the simulator. Depending on the nature of the study it might take place in an urban environment or on a closed track. The advantage of an urban environment is its clear applicability to a real world scenario. It might be necessary to run the study on a closed track for safety reasons.

4.2 Details of Proposed Research Agenda

The AIDA project is fundamentally a research endeavor with the aim of answering questions about the relationship and interaction between the car and its occupants. These questions are posed as research problems, and answered through the design and execution of human subject studies. These answers, which take the form of human response to specific aspects of the systems appearance and behavior, will lead directly to the design of more effective in-car communication systems. It is through this ability to make informed design decisions that the broader goals of the project might be achieved. These goals include enhancing the relationship/bond between occupants and car, increasing customer satisfaction and brand loyalty, and generally making the driving experience more effective, safe and enjoyable.

Because these are broad goals, specific factors must be identified that would lead to their attainment. One particular research area of seeming relevance and importance is that of attitude and behavior change. This relatively broad area would lead to the identification of specific aspects of the systems appearance and behavior directly correlated with predictable and significant change in driver/passenger attitude and behavior. For example, it might be found that by directing AIDA to greet the driver upon entering the car, the driver might be more willing to comply with an unrelated subsequent request (such as buckling a safety belt).

An initial study might be structured to test the ability of different configurations of the AIDA system to elicit compliance with some request. The configurations being compared might include AIDA physically active during a request, partially active, fully embedded in the dash or not present at all. In the case of not being present a traditional communication method might be used such as a beeping or blinking symbol. The conditions being tested would be the *independent variables* in the study, or the variables being actively and intentionally changed by the experimenter.

In order for the study to be meaningful, a *dependent variable*, or measurable result, must also be incorporated. It would probably be desirable to have both a behavioral and questionnaire based way of measuring the effect of the independent variables. The behavioral measure might be the subject's willingness to perform a tedious driving task specifically requested by the car. An example of a tedious driving task might be the frequent need to pull over and perform a number of boring tasks in the midst of a normally fun and exciting driving game.

In the control condition, with no requests made, the subjects should consistently avoid performing the tedious task. The measure of the effectiveness of the various independent variables (in this case configurations of the AIDA system) would be the frequency with which they successfully lead drivers to perform the tedious task during the driving exercise. The hypothesis for such a test would be that drivers would comply more often with requests made by the AIDA system to perform the tedious task as compared to the traditional interface. Among the AIDA systems it is hypothesized that drivers would comply more often with the physically moving case, as compared to the non-moving case.

In addition to the behavioral dependent measure, it would also be desirable to measure subjects' attitude towards the car and AIDA system using a text based questionnaire. Such a measure would allow some insight into the subjects' perception of the system and experience along a number of dimensions. These dimensions might include the credibility, trustworthiness, likeability, or intelligence of the system. It might also be desirable to ask the subject how much they enjoyed having the system in the car, whether they would want a similar system in the future and what general comments they might have. It is important to attain these measures in order to avoid the possible scenario of successfully changing driver behavior, but negatively influencing their mood or attitude in the process.

This type of study, and its many variants could be performed using either a simulation system, or a real driving scenario. The simulation might be set up as an enjoyable drive with beautiful scenery. The driver's general goal might be the relatively easy task of locating a number of landmarks. In this case the tedious tasks might require that the driver pull off the road and perform some kind of mental agility test such as math/logic problems, or perhaps they would have to search through extremely detailed reports of the car's performance (a very long spreadsheet) for subtle abnormalities. In the physical driving scenario the driver might be on a track or in an urban setting again following some relatively simple set of instructions. In this case the tedious task might require them to physically pull over and actually inspect a number of areas of the vehicle. This could be made arbitrarily tedious by increasing the number of checkpoints, and including difficult to reach spots under the car.

4.2.1 Applications for Behavior Change Research

The research study described above, and those with similar aims, would lead to a greater ability to change driver behavior. There are many applications for behavior change within the driving environment. Some examples are described below.

AIDA as Communication Conduit

With some exceptions, the car's desire for the driver to perform a specific action is expressed using flashing symbols and beeping sounds. In some cases this works as an ambient channel of communication, though in other cases it might actually be harmful to the relationship between driver and car. The alert that sounds in response to unbuckled seatbelts for instance, is more akin to coercion than anything else. A sound, designed to be irritating, is continually played until the driver or passenger reaches a threshold of tolerance and eventually complies with the car's request. The result in this case is a subtle, or in some cases very explicit resentment of the automobile, and consequently a deterioration of the relationship between the car and its occupants.

A result of this work would be alternative ways of requesting that the driver buckle their seatbelt, or check their engine, fill their gas tank, close the door, etc. It might be possible to, for example, suggest to the driver that their seatbelt be buckled by designing a socially expressive interface to look increasingly nervous or concerned for the driver's safety. If designed well, the result might be that the car's concern for the driver's safety would motivate the driver to buckle their seatbelt, rather than being coerced by an irritating sound.

This same type of communication could be used to indicate the gas is low, headlights are off, or that the car should be taken for routine maintenance. Though not all of these are as inherently irritating as the traditional seatbelt request, they can be used as opportunities to improve the relationship between driver and car. This improvement would be the result of the car providing useful information in a way that shows a concern for the driver's well being.

AIDA Will Save Your Life

Other applications of this research in human-automobile interaction might revolve around safety. Most accidents are the result of dangerous, or irresponsible driver behavior which are themselves the result of bad habits. These habits continually receive false positive-reinforcement because of the lack of feedback during the driving experience. In other words, each time a dangerous behavior fails to lead to an accident, its perceived risk is decreased. In reality, the more often a driver performs some dangerous behavior, the more likely they are to suffer a severe consequence. This dangerous cycle could be avoided if there was some system present in the automobile capable of providing feedback in real time in such a way as to fundamentally change risky habits.

The validity of this belief is validated by companies such as *DriveCam* that use systems in the car to monitor drivers. Upon the detection of an anomalous event a device coupled with two video cameras records the 10 seconds preceding and following the event. Later, these events are processed and the driver receives feedback at a later time with a trained consultant.

In this proposed application of the AIDA system, the driver would receive feedback in close to realtime (as soon after the event as is safe and appropriate). The introduction of this form of realtime feedback into the car could completely change the concept of accident prevention.

Currently accident prevention is primarily thought of as a physical action taken by some system in the car directly before a potential collision is detected. In the most modern vehicles these actions might include providing an alert as to the presence of a driver in the blind spot, or even physically controlling the vehicle to prevent a collision during a lane change.

Though the realtime methods of accident prevention are vital, and have the potential to save many lives, they are in some ways a patch or superficial fix for a more fundamental behavioral problem. By addressing unsafe driving at a behavior level, Audi is in a position to fundamentally change the way we think about in-car safety. A future is possible where car's actively work to make drivers safer, and in doing so improve the relationship between car and driver, making the driving experience more enjoyable and rewarding.

AIDA as Captain Planet

Another benefactor of the ability to change driving behavior might be the environment. The newest Audi navigation systems are capable of suggesting low carbon emission optimized routes, though there is no external motivation for them to make such choices. Other driving behavior is also known to significantly increase carbon emissions, such as unnecessarily fast accelerations. If these were discouraged in such as way as to maintain the driver-car relationship, but also decrease carbon emissions, a significant positive environmental impact might be achieved.

AIDA as Text Message Interface Promoter

Recently released research has revealed a robust risk revolving around receiving and replying to text messages while riding. Because of the substantial danger associated with text messaging, this behavior should be addressed in some way. It seems clear that legislation will eventually attempt to deal with this as individual states slowly catch on, as they currently are with cell phone usage. The increasing media coverage, and eventual public pressure will also potentially drive automobile manufacturers to deal with this issue. One way of decreasing amount of text messaging while driving might be to combine an automated response system with an interface such as AIDA.

The automated response system would give the driver the option of sending a predefined message in response to one received. An especially intelligent system might even have the ability to send messages catered to specific senders in specific contexts. For example, if the system is able to connect the current destination with a person, and a message is received from that person, then a suggested automated response might read: "Can't talk. Driving. ETA: 15min."

As useful as an automated response system might be, drivers will only use it if they are motivated in some way. It could be the role of an AIDA like system to encourage drivers to respond using the automated system, and discourage risky texting behavior while driving. It might even be possible to encourage the passenger, if present, to deliver the response to an incoming message in order to decrease the cognitive load on the driver.

AIDA: Keeping You Awake

Particularly dangerous behavior such as falling asleep at the wheel could be dealt with in a number of novel ways. Current research being conducted at the ERL is looking to detect sleeping drivers. This information, fed into a social interface, would enable behavior designed to keep drivers awake, or encourage them to pullover and take a nap.

4.3 Summary

A timeline for the next two years of the Audi Sociable Car project has been proposed with initial milestones working toward the completion of a user study. The successful execution of the study will require the development of sensing and software systems for the AIDA platform and a driving simulator. The goal of the research study will be to explore the efficacy of an in-car social interface, specifically with regard to changing human belief and behavior.

The results of the research should lead to the development of a second version of the AIDA system, suitable for installation into a vehicle provided by Audi. Integration of AIDA V.2 into the vehicle will be a technical collaboration between PRG and and the ERL, culminating ultimately in a second test of the improved AIDA system.

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