A Collaborative Approach for Human-Centered Driver Assistance Systems

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Abstract –

This paper describes an interdisciplinary research collaboration to design a human-centered driver assistance system. Driving behavior is captured using a novel intelligent vehicle test bed. The synchronized capture of driver behavior and driving context provides an empirical basis for design and evaluation.

1 Introduction

Designing an effective intelligent driver support system (IDSS) requires understanding how drivers make sense of their driving experience and active interdisciplinary collaboration throughout the design process. Real-world studies of driving and what information drivers rely on to make decisions and act are essential. These studies require sophisticated test beds to capture synchronized data of driving behavior and context, analysis tools for video and other time-based data, and architectures for implementing real-time intelligent driver support systems. The LISA-Q Intelligent Vehicle Test-Bed [1], shown in Figure 1, supports capture of driver behavior and exploration of real-time algorithms for IDSS.

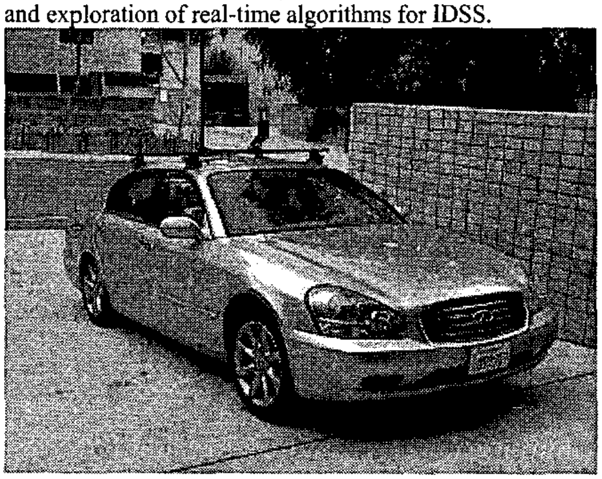

Figure 1 The LISA-Q Human-Centered Intelligent Vehicle Test Bed

2 Previous Work

Most behavioral analysis efforts involve simulator studies. Research groups such as those at the University of Michigan's Transportation Research Institute have used simulators and instrumented vehicles to test driver behaviors in specific situations [2, 3]. While simulator studies permit construction of highly controlled situations, generalization from performance in simulators to real world driving is problematic. A simulated environment cannot reproduce the complexity of the real world. It does not provide the rich context of real-world driving: a destination and purpose, distractions, social involvement with passengers, etc.

Several vehicle test beds have been developed [11, 12] both to test context detection algorithms and to study driver behavior in actual driving situations. As with data collection in a simulator, studying real driving requires more than simply recording behavior. It requires determining the meaning participants assign to it. Further analysis is required to determine how drivers understand the situation they are in, what their expectations are, and what preferences (e.g., towards traffic or technology) influence their behavior. These all affect how drivers respond to their surrounding context and how they may use driving support systems.

Finally, while a number of studies have focused on the driver's perspective [7, 8, 10], most are analyses of carefully chosen case studies and none had access to the detailed synchronized records of driving behavior and context that can be recorded in the LISA-Q. In addition, our work is unique in emphasizing collaboration between engineers researching driver support system sensor technologies and test beds and ethnographers studying driver behavior. Data collection is achieved through the same test bed and data analysis relies on shared tools. In the next two sections, we describe the development of our shared test bed, data collection, and analysis tools.

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3 The LISA-Q Data Collection Architecture

Cognition is *distributed* [5] and *situated* [6]. Understanding cognition requires understanding the interaction between mind, body and material world. This means that to understand driving necessitates capturing the context of the activity and his insertion in driver's course of action. The LISA-Q test bed [1] provides a modular scalable architecture for capturing driver context. The architecture for this system is shown in Figure 2.

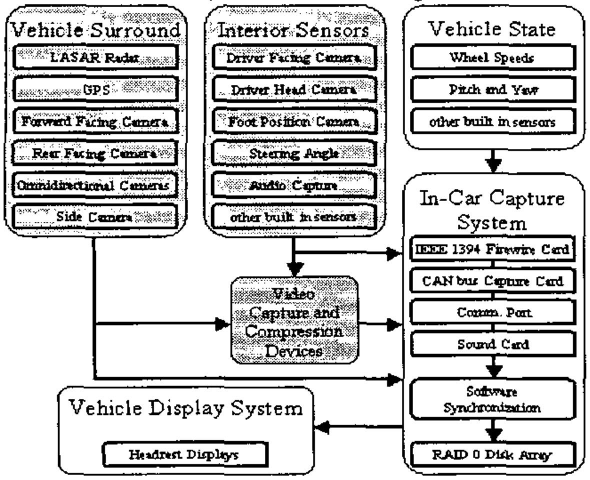

Figure 2 The LISA-Q complete context capture system architecture

Video streams provide information on the vehicles surround using forward, rear, and side viewing rectilinear cameras as well as an omnidirectional camera that provides a 360 degree view. A near-IR camera with IR illuminators captures the driver's foot actions, a camera facing the driver captures the driver's face and hand movements, and a camera mounted on a driver-worn headband provides the driver's view. These video streams are all captured, compressed, and time-stamped in real time using external DV compression hardware and an x86-based data capture computer located in the trunk of the vehicle. Figure 3 shows samples of the captured video streams.

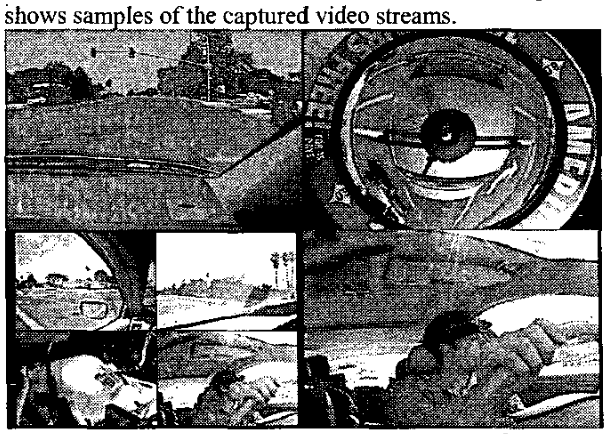

Figure 3 Video streams collected by the LISA-Q capture system

GPS is collected via a serial port interface to the computer. The GPS information is useful in obtaining the drivers current location and progress towards their destination.

Vehicle information is collected via a CAN bus interface between the vehicle's internal computer system and the data capture computer. The vehicle itself captures information on steering angles, pedal positions, LASER RADAR readings, and vehicle dynamics information.

3.1 Additional Ethnographic Data

A principal objective of behavioral analysis is to uncover categories of driving situations and models of technology that are meaningful to drivers. For example "lane changing" is an engineer-defined category that encompasses several different categories for drivers, with corresponding information needs and behavioral sequences (see section 5). By determining categories meaningful to drivers we expect to be better able to assess how they match system functionality and drivers' expectations.

Identifying driver's perspective on the drive needs more data than the behavior and the surrounding, already automatically captured by LISA-Q. Additional data, especially from driver's comments, are gathered before, during, and after driving. Each driver fills out a series of survey questionnaires. Two are filled out before the drive: one is dedicated to the subject's driving history, the other is intended to determine whether they are risk-averse or risk-seeking drivers. After a drive, additional questionnaires are completed. They focus on the evaluation of the Q45's Active Cruise Control. All the questionnaires we use are identical to the ones used in prior simulator studies, to facilitate comparisons [9]. While driving, drivers are also asked to comment on their current actions aloud and are frequently prompted for explanations of their actions. Subjects are called back to the lab for a debriefing interview a few days later. This permits review of the videos to locate events that might benefit from further questioning the participants. During this final interview, drivers are asked for more detailed comments on these events, as well as to reflect on the drive as a whole, their habits and preferences, and various general issues such as their acceptance of technology.

3.2 Data Collection Procedure

Full data sets have been collected from fifteen drivers using the LISA-Q test bed. Two forty-minute routes were chosen to observe both freeway and surface street driving situations. Drivers were accompanied by a navigator to make them feel comfortable and confident, in order to collect more natural data. For each drive:

- A preparation phase included instructions to the driver and the preliminary questionnaires.
- During the drive, one observer was sitting in the passenger seat, giving the driver directions and prompting them to describe their actions. Another

researcher sat in the back, monitoring the data capture process and taking notes about activity in or around the car.

- Right after the drive and before leaving the car, drivers were asked questions about their overall experience, the most memorable moments of the drive, as well as their impressions on the Active Cruise Control.
- Following this, a second series of questionnaires was filled out by the driver.
- Finally, a few days after the drive, the debriefing interviews were completed.

4 Data Processing and Analysis

Analyzing the behavior from driver's perspective requires situating their observable actions in the context of their environment and in the longer term of their course of action. For that purpose, it is necessary to go from the very rich representation provided by the movies to a synthetic representation that integrates context and behavior. Several tools, coding schemes and representations were developed to support the different steps of data processing.

4.1 Contextual representation

Reviewing the video is one important part of the analysis. Post-processing is used to combine the video, audio, and sensor streams. It greatly helped this work by providing a clear and contextually enriched rendering of the situation.

The tools developed to help extract and display this information include generating a surround map based on an inverse perspective projection of the cameras, an aerial view of the vehicles location, lane position information, and other metrics. Figure 4 shows a frame from a post-processed video which combines the synchronized video, GPS data, CAN Data, and lane tracking [4] to display the current context of the driver.

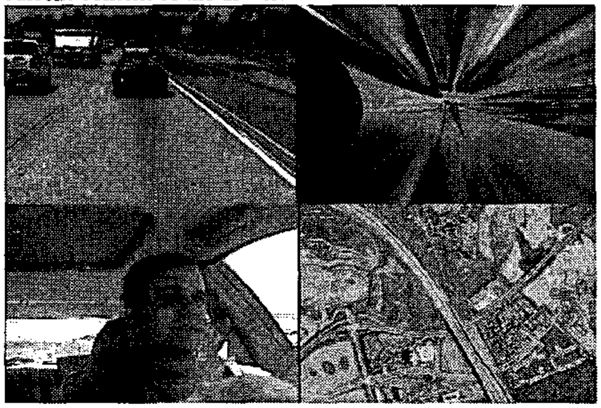

Figure 4 Video post-processing showing the video streams synchronized with GPS information and an aerial map as well as a local map constructed from the surround videos

4.2 Timeline representation

Once an interesting situation is identified, different fluxes of data are represented into timelines. Several algorithms were developed to automatically extract and plot data in such a way, completing the data from the canbus. They provide some of the necessary behavioral and context measures and limit the amount of hand coding.

The Figure 5 shows a snapshot of the tool used to view this processed information along with the synchronized CAN-bus and GPS data.

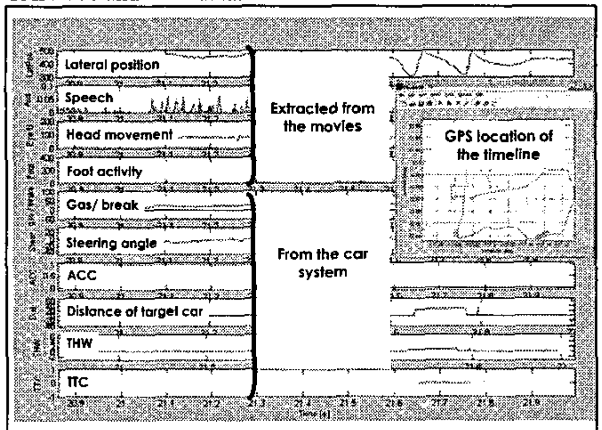

Figure 5 Timelines gathering data from the CanBus and extracted from the movies. The corresponding GPS location of this segment is shown according to the whole route.

The representation of the lateral position provides a direct access to the lane changing events. The close examination of the behavioral data has also shown the interest of looking at the looks on the mirrors and at the foot activity, including hovering. The representation of the lateral head movement and of the foot motion gives immediate and good indications of such behavior.

4.3 Synthetic representation of situations

Diagrams are built to identify how the driver behaves according to the context of his situation. An interpretation of the data provided by the timeline and hand coding is synthesized and checked against the richer information provided in the processed videos. Information from the driver's comments (from the driving session, the post-session chat or the interview) on their own behavior and on the situation's context is also incorporated into the interpretation of the events. As these additional ethnographic data (see section 3.1) are not automatically time-stamped (unlike the data collected by the LISA-Q test bed), they need to be indexed with a time code that corresponds to the driving event they refer to (and not they own time of occurrence), in order to be integrated with the automatically extracted data. Figure 6 shows an example of these diagrams.

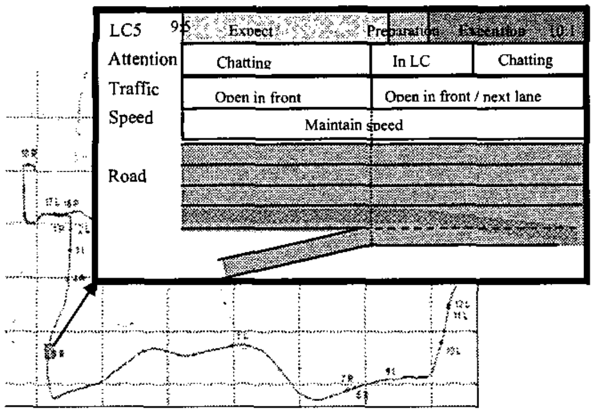

Figure 6 Representation of specific situation that shows the lane changing process and the driver's attention according to road and traffic context

This specific example shows how the driver stops chatting at the moment when a new lane arrives on his right to prepare his lane changing, looking on the side mirror and over his shoulder, and to execute it. The rapidity of attention shift and of the execution is explained by the fact that 1) there is little traffic to disturb the driver and 2) he was already expecting an exit on his right (being told directions just before).

5 Behavioral Analysis

As an example how the dataset described above is exploited, we will present results from an analysis focused on lane changes. Lane changing is an important issue for obvious safety reasons. As a common driving event, it could be supported by IDSS that could make it safer and more comfortable. From the driver's perspective, changing lanes is a delicate operation: one has to find a spot to safely reach their target lane, while keeping track of the traffic in their own lane, remembering their route, possibly staying engaged in a conversation, etc.

Our analysis has shown that different lane change configurations imply different information needs for the driver, and influence their sequence of behavior.

5.1 Configurations of Lane Changes

Three configurations can be characterized, based on the element of the environment whose perception by the driver brings the need for a lane change in their course of action: the constraints of the road, the traffic and the driver's route.

Firstly, a lane change can be provoked by the need to conform to the road's constraints, in order for the driver not to drive off-track. This is the case when the road configuration is changing, for instance when the lane the driver is driving in ends, or when temporary road works obstruct that lane. This could also happen when the driver finds himself in a bad position.

Secondly, the driver can wish to change lanes because of the traffic, in order for them to get more stability or more speed. Examples of this include: moving to the left lane to avoid braking for cars merging into the highway, weaving between lanes for speed, passing a truck, etc.

Thirdly, the lane change can be imposed by the need for the driver to follow their route in order to arrive at their planned destination. Examples of this include: moving to one's right on the freeway to be able to catch an upcoming exit lane, moving to or out of a freeway exit-only lane, etc.

For each of these configurations, an element of the environment gets more weight for the driver and frames his interpretation of the situation. This doesn't mean that the others element of the environment are not taken into account: if the driver changes of path to follow the road or his route, he still has to deal with the traffic.

5.2 Sequence of Driver Behavior for Lane Changing

The configurations have entailments for the sequence of behavior through which the lane change is executed.

The route and the road impose constraints on the appropriate moment to change lanes. For instance, one has to change lanes before the lane they are driving in ends. Taking a freeway exit often imposes to change lanes between two points, where the exit lane is available.

Drivers try to anticipate these lanes changes. When they do not know the environment, they are limited to the visibility provided by the landscape enhanced by the road signs. But when they are on a familiar route, they are able to anticipate the lane change and have more freedom about when to execute it, which is especially important when they need to deal with a lot of traffic.

Dealing with the traffic offers a huge space of possible decisions. Drivers are free to choose where and when it is better to go. They can form an intent, monitor traffic while waiting for an open spot in the target lane, postpone the execution and resume it later when an opportunity appears, based on the circumstances. As they develop habits, people reduce the variety of possible decisions: systematically avoiding specific vehicles like trucks, choosing the fastest left lane, being more or less aggressive to wait or force one's way into an open spot, etc.

In almost all lane changes, the driver presents a behavioral signature, composed of a sequence of looks to the side and over their shoulder when beginning the execution.

Dealing with the constraints of each configuration, they can also show other sequences:

- monitoring period to get a spot
- accelerating/reducing to adjust speed get a spot in targeted lane / to deal with slow vehicle ahead
- releasing situation to leave time to get situation

5.3 Informational Needs of the Driver

The distinctions discussed in section 5.1 are also important because they imply specific informational needs, which directly affect the design of driver assistance systems.

Any of these configurations requires dealing with the traffic. Once his intent established, the driver has to determine "where and when is the spot to go on my targeted lane?". He uses the information on the cars around him and their relative speed to response to this question. But this interpretation is framed by how his intent is formed, according to the configuration of his lane changing.

When his lane changing is done to adapt to the traffic, the first question for the driver is: "where will I have my best drive?". The easiness of the spot is evaluated according to the interest of the target lane. In others words, the traffic creates both the goal and the solution for the lane changing.

For the configuration centered on the road constraints, the driver firstly has to use the signs and lines to determine "where I am allowed to go?". The information on the traffic is used then to choose between the options and to find the right moment.

When he is looking for his route, the driver needs information about directions in order to establish "where should I go?" and, possibly, to change of lane. He will have to pay attention around him (map, signs, indications by someone else or a navigation system), which could be an important factor of distraction.

6 Conclusions

User-centered perspective and ethnographic approaches to studying human behavior have been gaining acceptance in the context of technology design yet these very approaches face serious challenges from the design and engineering communities. Often the studies remain at an anecdotal or case-study level and are difficult to generalize to larger populations of users. On the other hand, simulator-based design efforts have suffered from being too simplified compared with the richness of real-life driving situations.

To our knowledge, this is the first time ethnographers and engineers collaborating on the design of a IDSS join efforts in every step of the process from data collection to data analysis (using the same data!) and share both a test-bed and analysis visualization tools. In a true dialectical fashion both groups of researchers were influenced by the interaction dynamics to produce results and new questions that would not have emerged if each group worked on their own.

The benefit of this collaboration to the development of successful technology (in terms of acceptance by a consumer population) can not be overlooked. The direct link such a collaboration provides to how user think and feel about a technology (as well as how they behaviorally react to it) and to how they make sense of their experience, may support a shortened cycle between R&D activities and bringing a successful design to production. In the realm of improving safety on the roads, any contribution to a quicker development cycle is well worth striving for.

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