

# Design of an Instrumented Vehicle Test Bed for Developing a Human Centered Driver Support System

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## Abstract

*In this paper we introduce a new type of intelligent vehicle test-bed that is enabling new research in the field. This new test-bed is designed to capture not just a portion of the vehicle surround, but rather the entire vehicle surround as well as the vehicle interior and vehicle state for extended periods of time. This is accomplished using multiple modalities of sensor systems so that it can form a complete context of the vehicle. This allows new research to be performed in intelligent vehicle algorithm development and allows studies in driver behavior to be performed. We also show results from some of the research being performed using this test-bed.*

## 1 Introduction

Many researchers are currently working on the problem of making our highways safer for driving. One method of providing this safety is to examine the link between the driver and the automobile to see what modifications can be made to the automobile to assist the driver. This includes advanced warning systems and improved user interfaces. In order to warn the driver of potentially dangerous situations such as vehicle cut-ins, driver distraction, driver drowsiness, problems with the vehicle, and unintended lane departures, a complete vehicle context is required. This complete vehicle context includes the vehicle surroundings, vehicle interior, and vehicle state. At the backbone of this research is the creation of a human-centered intelligent vehicle that captures this complete context and interacts with its occupants to inform or warn the driver of potentially dangerous situations.

In order for this research to progress, an intelligent vehicle test bed must be created to accomplish the tasks of 1) collecting data on driver behavior in order to best respond to various situations and better understand the

drivers intent, 2) testing algorithms for sensing the vehicle context, including its interior, and feeding that back into the vehicle's user interface, and 3) collecting complete surround data (both interior and exterior) in order to create an annotated ground truth data set for training of intelligent systems. The system described here, the Laboratory for Intelligent and Safe Automobiles – Q45 (LISA-Q) test bed, based on an Infiniti Q45 car model (Figure 1), is the first intelligent vehicle system that fully accomplishes these tasks.

The LISA-Q test bed focuses on creating a system capable of collecting large amounts of data from a variety of modular sensing systems and processing that data in order to be fed back to the human occupant. Sensor systems include rectilinear cameras, wide field-of-view camera systems, GPS and navigation systems, internal automobile vehicle state sensors, as well as other sensor systems useful for study in intelligent vehicles. The system contains an array of computers that serve for data collection as well as real-time processing of information.



Figure 1 The LISA-Q Test Bed

## 1.1 Previous Work

There have been many other vehicle test-beds that have been built for research into intelligent vehicles [1]. These vehicles are mostly built for autonomous driving and or data collection with one specific purpose or algorithm in mind, or only capture a portion of the vehicles context, both interior and exterior. In our approach we intend to fill in the gaps between various data modalities and algorithms by creating a test bed that has complete sensor coverage of the surround, the interior, and the vehicle itself.

Active research has been performed in using various sensors to create automated vehicles. One popular way to detect objects and navigate is through rangefinder sensors and GPS. Carnegie Mellon's NAVLAB [2] offers solutions for curb and people detection by using SIIC sensors and video for driver feedback. At the University of Minnesota, GPS is being used exclusively to guide busses on shoulder lanes of freeways. Other researchers have used vision-based systems to help develop research in this area. Nissan Motor Co. has developed a testbed [3] that uses both vision and embedded magnetic lane markers for lane keeping and collision avoidance (both from obstacles and lane departure). University of Parma's ARGO [4] used its stereo camera pair to do lane detection and localization of obstacles. The Australian National University Intelligent Vehicle Project used camera based lane tracking and obstacle detection. At the Institut fuer Systemdynamik und Flugmechanik, MarVEye, a camera array unit, is tested in VaMoR [5], a truck. It was used to autonomously drive the vehicle on rural roads. The University of Michigan Transportation Research Institute equipped a Honda accord with lane tracking and driver monitoring cameras in order to perform human factors research [6]. Other such systems and algorithms can be found in a recent survey by V. Kastrinaki, M. Zervakis, and K. Kalaitzakis [1].

The LISA-Q attempts to go beyond these systems by providing a system for complete synchronized context capture. This allows the LISA-Q test-bed to be used not only for surround analysis such as lane detection and obstacle detection, but also for monitoring driver behavior and state [7] as well as the vehicle state. By using the complete context of the vehicle surround, vehicle interior, and vehicle state, we can develop driver assistance systems that are more human centered.

## 2 Vehicle and Surround Information Capture

The LISA-Q information capture system is designed to obtain complete coverage of the vehicle surround, the vehicle interior, and the state of the vehicle for extended periods of time. This is achieved by a variety of sensor

systems including rectilinear cameras, omnidirectional cameras, laser radar, microphones, and internal vehicle sensors. Figure 2 shows the LISA-Q information capture system

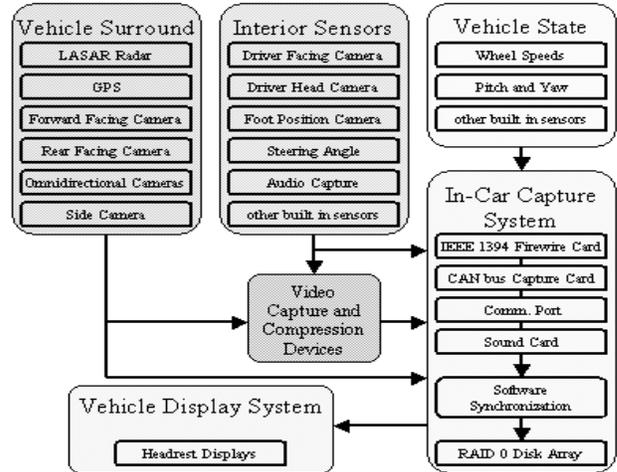


Figure 2 The LISA-Q Information Capture System

### 2.1 Vehicle Surround Capture

One of the requirements of an intelligent vehicle is to have information of the vehicles surround. For our test bed we have divided the vehicle surround into six sections, in front of the vehicle, to the rear of the vehicle, and both a front side and rear side for both the driver and passenger side of the vehicle. We can then choose sensors to get full coverage of the sections and assign importance to sections in building a surround map of the vehicle. Figure 3 shows these divisions. For instance, the front section should include an area at least 80 meters in front of the vehicle, while the side sections need only extend 15-20 meters in order to capture lanes adjacent to the vehicle. Rear surround might contain less important data to the intelligent vehicle there by reducing the necessary resolution or coverage area.

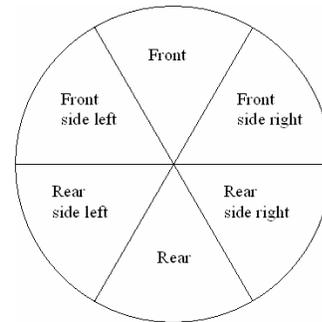


Figure 3 Vehicle Surround Coverage Segmentation

To attain the external surround coverage, many types of sensors are used. The wide field of view camera (omnidirectional vision sensor [8]) covers the short range (approximately 15-20 meters) in every segment. Front is further covered by a stereo pair of rectilinear cameras and a five beam laser range finder. Two rectilinear cameras cover the rear side left, rear, and rear side right. Figure 4 shows the layout and field of views of these sensors.

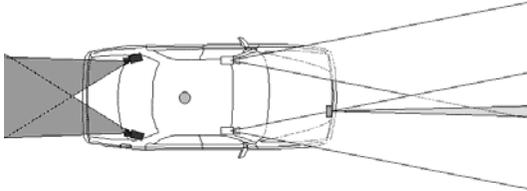


Figure 4 External Surround Sensors (Laser Radar, Front Rectilinear cameras, Omnidirectional Vision Sensors, Rear Rectilinear cameras).

## 2.2 Vehicle Interior Capture



Figure 5 Top left: head cam capture; Top right: rear cam capture; Bottom left: Foot cam (note floating foot over brake pedal); Bottom right: Face Cam

In order to provide driver/occupant analysis, the interior of the vehicle must also be captured (Figure 5). This is important for human behavior study in order to get information on the drivers state and decision making processes. The interior context also plays an important part in many intelligent vehicle systems [7, 8, 9].

In order for the interior capture system to be useful in these applications it must be unobtrusive so that it does not affect the behavior of the driver. Therefore cameras visible to the driver must be small or partial hidden from view.

To attain internal coverage discretely, several video sensor types are used. To estimate current sight attention, a rectilinear headband camera (dubbed the subcam) is used. For capturing foot movement and hovering over each pedal, a near infrared sensitive black and white rectilinear camera with infrared illuminators is used. These video feeds are important for behavioral analysis studies because they provide information on the driver's actions. These combined with the vehicle surround and vehicle state help build a complete context for understanding driver behavior.

## 2.3 Vehicle State Capture

The vehicle state can contain information valuable to determining human behavior and driver intent. Furthermore, vehicle state variable such as vehicle speed, steering angle, and so on can be useful for tracking ego-motion [10] and other algorithms for surround capture. Positional data obtained from GPS is also useful for determining the surround context based on maps. This is important for both the behavioral studies to get the drivers context as well as surround analysis algorithms to provide more information on the vehicles context (i.e. Highway, city streets, intersections, etc.)

This information is available on the Infiniti Q45 CAN data bus. CAN capture is accomplished using LabView and a National Instruments NI-CAN capture card. The CAN bus data provides vehicle information including but not limited to speed, acceleration, braking, yaw rate, and distance to lead vehicle information from the Laser Radar system. The output of this system is time-stamped with the system time in milliseconds for synchronization with other sensor streams.

GPS is captured using a Garmin GPS system connected to the data capture computer's serial port. The serial port is accessed and the data is parsed using software written explicitly for the LISA-Q data capture.

## 3 LISA-Q High-Bandwidth Sustained Data Capture System

In order to collect data for use in behavioral studies, the LISA-Q test-bed must be capable of collecting multiple video and data streams for periods of about 1 hour. The LISA-Q system addresses the problem of sustained high-bandwidth synchronized data capture by using real-time hardware compression and an integrated computer system for data capture (See Figure 2). In order to capture the complete vehicle context we require at least 4 full frame NTSC video streams as well as CAN bus data, GPS data, and audio data. Some of the video streams which are used for behavioral studies analysis but not algorithmic development can be combined into a quad stream like that

in the lower left corner of Figure 6. Using one quad stream allows us to obtain 7 video streams in the same bandwidth as 4 full frame video streams.

Four full frame video streams in uncompressed RGB format take roughly 120 Megabytes/sec of bandwidth. Collecting data for a typical 1 hour run would then require 428 Gigabytes of data storage. This is too much bandwidth and capacity to make an uncompressed system feasible.

Because of this, in the LISA-Q, we pipe the video streams through high quality DV converters to compress the data in real time while still preserving image quality. The result is a 25 megabit/sec bandwidth per video stream that will allow us to expand the capture system to 8 full frame video streams and beyond. This allows multiple data streams to be collected for long periods of time, thereby allowing extended off-line testing of algorithms and behavioral analysis studies.



Figure 6 Video data taken from the Q45 Test Bed. (Upper Left – Front View, Upper Right, Omnidirectional Vision Sensor, Lower Left – Rear View/Subject Camera/Near-IR Foot Camera, Lower Right – Subject Camera.)

## 4 Algorithms and Results

By capturing the complete vehicle context, we have a large amount of information present for developing intelligent vehicle algorithms. These algorithms can take advantage of information provided by many different sensors to create a more robust intelligent vehicle.

### 4.1 Driver State Analysis

In developing a human-centered intelligent vehicle, occupant analysis becomes an important area of research. By analyzing the driver's state, the vehicle can respond more appropriately when critical situations occur. For example, if the driver is showing signs of drowsiness or talking on a cell phone, the vehicle might warn the driver earlier of an impending critical event. Figure 7 shows results from driver state analysis in the LISA-Q test bed. The surprise icon in the lower right hand corner of the

figure is generated by tracking points on the drivers face and classifying them based on a pose-invariant classifier.



Figure 7 Driver State Analysis in the LISA-Q test bed

### 4.2 Robust Lane Tracking

One part of generating a higher-level context for use in both behavioral and driver assistance algorithm is lane detection. Because the LISA-Q has multiple overlapping sensors, it is possible to combine results from multiple algorithms to create a better estimate of the vehicles orientation within the lane. Figure 8 shows the output of two different lane detectors used in the LISA-Q test-bed. The image on the left is from an algorithm designed for rectilinear cameras for use with Botts Dots lane markings while the image on the right is a Hough transform based lane detector based on a de-warped omnidirectional image.



Figure 8 Lane detection using the LISA-Q test bed for both rectilinear (Left) and omnidirectional (Right) vision sensors.

### 4.3 Obstacle Detection

For the LISA-Q Test-bed to effectively aid the driver, obstacles must be detected in the surroundings. Wheels are good candidates for detection because they are present on all vehicles. Using the omnidirectional camera (Figure 9, left), perspective views are generated for exterior passenger and driver side views. The frames are convolved with a basis of derivative of gaussian filters generating high dimensional representations of wheels [11]. These are detected (Figure 9, right) and car locations are inferred.

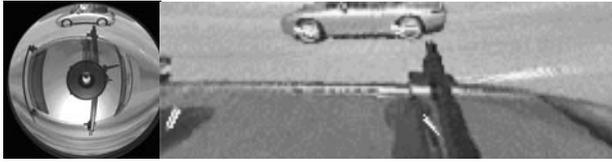


Figure 9 Object detection using an omnidirectional vision sensor (Left - Raw image corresponding to processed image, Right - arrows facing in direction of motion relative to camera.)

#### 4.4 Data Visualization

In order to study driver behavior, it is important to be able to generate a surround map showing the relation of the vehicle to the road and other vehicles. This eases the study of why drivers make decisions in certain scenarios. In Figure 10 below, the omnidirectional camera is de-warped using the flat-plane transform [12] and overlaid with an inverse perspective image generated from the front looking camera. A line signifying the vehicle's current trajectory with black time headway markings every half-second is drawn along with the lanes and lead vehicle location.

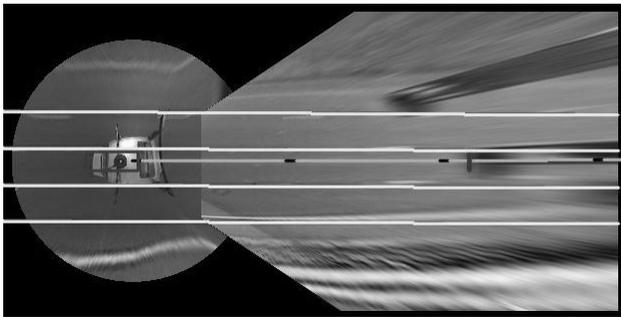


Figure 10 Surround map generation from surround sensors, vehicle state sensors, and computer vision algorithms.

Figure 11 shows a program created for visualizing the data collected by the LISA-Q developed by Evan Schumacher at the Computer Vision and Robotics Research Laboratory. The program is capable of displaying video warped using the inverse perspective and flat plane algorithms as well as graphing data taken from the vehicles internal sensors corresponding to the video being displayed. Other functionality such as searching for events and playing audio recorded during a drive make it valuable as a tool for human behavior analysis.

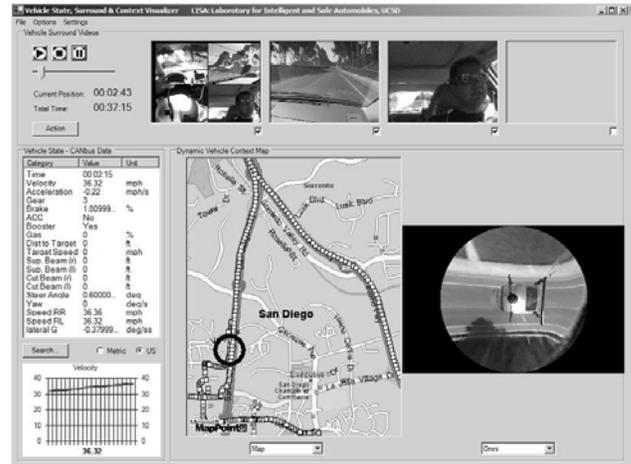


Figure 11 Visualization of data from the LISA-Q Test Bed.

#### 5 Conclusions

We have shown that in order to address the problems faced with building a human centered intelligent vehicle, a new type of intelligent vehicle test-bed is required. The LISA-Q is designed for this research area and is enabling development of algorithms and allowing others to study aspects of driver behavior that could not have been studied previously. The LISA-Q is a novel test-bed focused on developing human-centered intelligent vehicles capable of capturing the complete context of the vehicle for long periods of time.

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