Road Departure Crash Warning Field Operational Test
(RDCW FOT)

Interim Report on Road Departure Crash Warning Subsystems

September 5, 2003

University of Michigan Transportation Research Institute

Visteon Corporation

AssistWare Technologies, Inc.

Table of Contents

INTERIM REPORT

ROAD DEPARTURE CRASH WARNING SUBSYSTEMS

INTRODUCTION

This document constitutes the Interim Report on RDCW Subsystems, as a deliverable within the Intelligent Vehicle Initiative's Road Departure Crash Warning System Field Operational Test (RDCW FOT). This FOT is supported by the USDOT under Cooperative Agreement No. DTFH61-01-X-00053. The agreement joins the USDOT with The University of Michigan Transportation Research Institute (UMTRI) and its industrial partners, Visteon Corporation and AssistWare Technology. The Interim Report is specifically focused upon the subsystems of the RDCW system, itself. It seeks to provide an update on the intent, scope, design, and status of each of six subsystems which are to be implemented on each of the FOT fleet vehicles.

The report is organized to address each of the following subsystems, per the section numbers indicated:

Section 1.0 – Lateral Drift Warning Subsystem (LDW)

Section 2.0 – Curve Speed Warning Subsystem (CSW)

Section 3.0 – Radar Subsystem

Section 4.0 – SAM Subsystem (SAM)

Section 5.0 – Driver-Vehicle Interface Subsystem (DVI)

Section 6.0 – Data Acquisition Subsystem (DAS)

The report also includes a system architecture diagram, Appendix A, which situates each of the above subsystems within the schematic for the overall RDCW system.

1.0 LATERAL DRIFT WARNING SUBSYSTEM

1.1 Role of the subsystem in Road Departure Crash Warning functionality

The role of the LDW system in the RDCW functionality can be synopsized as the following.

- Process forward-looking video camera data to:
  - Measure vehicle position and lateral velocity relative to lane
  - Measure lane width
  - Estimate improved shoulder width

- Use camera-derived info + modulatory info from SAM (e.g. available shoulder maneuvering room) to assess threat of lateral drift departure

- Forward threat level to DVI module for driver display/warning

A key goal for the LDW subsystem is to go beyond simple lane departure warning by modulating the warning onset to account for the available room on the shoulder to perform a recovery maneuver. If there is lots of shoulder recovery room, warnings will be delayed, to avoid nuisance alarms that often result from early warnings. But if little room is available beyond the edge of the lane for a recovery maneuver, warnings will be given early, in order to give the driver enough time to respond and avoid a crash.

1.2 Key Requirements impinging upon the subsystem

There are a number of hardware requirements for the LDW system, which we have explicated in detail during the system design process. A few highlights of these requirements include:

- A camera/lens combination capable of imaging road under a wide variety of weather and lighting conditions
    - Sufficient computing resources to support the required image processing, threat level assessment and communication functions
    - Communication link to SAM to support information exchange
    - Powered by 12-volt vehicle power

The primary processing requirements include the abilities to:

- Estimate vehicle position and lateral velocity relative to the lane
    - Estimate lane width
    - Estimate the width of the improved shoulder
    - Receive messages from SAM including available shoulder maneuvering room
    - Estimate level of threat of a lateral drift departure based on vehicle position/motion and available shoulder maneuvering room
    - Forward vehicle position/motion information, and drift threat level to SAM, for communication to the DVI

1.3 Architectural placement of the subsystem

The LDW subsystem has a single link to the remainder of the RDCW system (reference Appendix A – RDCW System Architecture). This link is an RS-232 serial connection to the SAM module. Information about the available shoulder maneuvering room is one of the primary pieces of information communicated to the LDW over this link. Information about vehicle position and motion, as well as the level of threat for a

drift departure are communicated from the LDW to SAM over this link. This information is forwarded from SAM to the DVI for driving the driver interface.

1.4 Hardware provisions (component selection)

The LDW hardware has been selected based on the SafeTRAC lane departure and drowsy driver warning system, available from one of the program partners, AssistWare Technology. The primary components of SafeTRAC include a very small (1"x1"x1.5") black and white video camera, which is mounted on the windshield behind the rear-view mirror looking out at the road ahead, and a processor to capture the camera image and process it to determine important scene parameters. The camera model selected is the VB4B by VisionTech, Inc. The processor SafeTRAC employs is the 21065 DSP from Analog Devices.

1.5 Software provisions

The LDW software consists of a single executable running on the 21065 DSP. Sixty times per second (every field) it performs the following functions:

- Captures video image of the road ahead

- Processes image to determine:
    - Lateral offset of vehicle in the lane
    - Lateral velocity
    - Lane width

- Width of improved shoulder

- Check for messages from SAM indicating:
    - Vehicle speed
    - Status of turn signal and brake
    - Road curvature data
    - Available shoulder maneuvering room ahead

- Estimate threat level for a lateral drift crash

- Communicate vehicle/road geometry info, and threat level to SAM.

While the software runs on the embedded DSP in the deployed system, for development and debugging purposes we have also developed the capability of running the same software on a PC running the QNX operating system. Among other things, this development system makes visualizing the system operation much easier.

1.6 Performance issues

There are four high-level performance challenges facing the LDW subsystem. They are reliable lane tracking, dashes vs. solid boundary detection, accurate and reliable shoulder width estimation, and balancing nuisance alarms and predictability.

1.6.1 Reliable Lane Tracking

The lane marking quality and the weather in the Detroit metro area (particularly in winter) pose significant challenges for a lane tracking system. Fortunately the image processing algorithm we are employing for the project is state-of-the-art, and is able to track the lane even when markings are of poor quality or obscured. To further mitigate the challenges of vision-based lane tracking, the SAM will provide information that will assist the LDW with its lane tracking function. This supplemental information includes upcoming road curvature, vehicle speed and turn signal/brake state. These inputs will provide the LDW with an idea of what to expect to see in the camera view of the road ahead, and thereby improve its lane tracking performance.

1.6.2 Dashed vs. Solid Boundary Detection

Discriminating between dashed and solid lane markers is another sensing challenge facing the LDW system. This task is made difficult, particularly in the Detroit area, by the "crack filler" material that is frequently used to patch seams in the pavement between lanes. Various weather and lighting combinations can conspire to make these filled seams between lanes look very much like a solid lane boundary, hiding the fact that in actuality, the marker between the lanes is dashed. The ambiguity associated with this situation could result in inappropriate behavior if a different warning was to be provided for crossing a dashed boundary versus crossing a solid boundary. For this reason, we have decided that the DVI will provide the same warning for crossing both dashed and solid boundaries.

1.6.3 Accurate and Reliable Shoulder Width Estimation

The extent of the improved shoulder, on which a recovery maneuver is possible, is a rather ill-defined concept. The true width of useable shoulder depends heavily on the pavement surface properties, not to mention the type and depth of material on the pavement (e.g. sand or snow). These factors, coupled with the fact that there is not always a strong distinction between the appearance of the improved shoulder and the off-road area, makes visually estimating the useable shoulder width a very difficult problem. To mitigate the impact of errors in shoulder width estimation, the LDW provides a confidence measure associated with its estimate. When LDW's confidence in its shoulder width estimate is low, the SAM discounts this information when computing the

available maneuvering room. If LDW's confidence drops low enough, SAM falls back on a default shoulder width for the current road type.

1.6.4 Balancing nuisance alarms and predictability

A real potential problem associated with sophisticated warning algorithms like the one being developed for lateral drift warning is that the complexity of the system's behavior may be misunderstood by the driver, resulting in confusion and dissatisfaction. Concretely, the variability in warning onset resulting from changes in available maneuvering room could be interpreted by the driver as "flaky" operation, and not necessarily intelligent or intuitive behavior. In short, sometimes drivers prefer simple, predictable behavior over more "intelligent" but harder to predict behavior. In order to mitigate the potential negative impact associated with unpredictability, we've chosen to limit the variability in the lateral drift warning threshold. So even if the available maneuvering room changes dramatically, the impact this will have on the LDW system's behavior as observable by the driver will be constrained so as to avoid the driver asking the question "why did it warn in situation A, but not situation B, which appears to me to be very similar?"

1.7 Status of subsystem development

All the major functions the LDW must perform have been implemented. These include:

- Capturing video images of the road ahead

- Processing images to determine:

    - Lateral offset of vehicle in the lane

    - Lateral velocity

    - Lane width

    - Width of improved shoulder

- Checking for messages from SAM indicating:

    - Vehicle speed

    - Status of turn signal and brake

    - Road curvature data

    - Available shoulder maneuvering room ahead

- Estimating threat level for a lateral drift crash

- Communicating vehicle/road geometry info, and threat level to SAM.

Ongoing activities include refining algorithms for estimating the improved shoulder width, and modulating the warning threshold to account for available maneuvering room.

Overall, the LDW hardware and software remains on schedule and is working well.

2.0 CURVE SPEED WARNING SUBSYSTEM

2.1 Role of the subsystem in RDCW functionality

The curve speed warning (CSW) subsystem determines the current vehicle position, predicts the most likely future path and determines the road geometry ahead by mapping the current vehicle position and heading from a GPS system to an enhanced digital map database. The role of the curve speed warning subsystem in the RDCW system is to issue a warning request when, based on the current vehicle position and speed, the required deceleration to achieve the maximum desired speed within the curve exceeds an acceptable level. The maximum desired speed within the curve is based on an associated lateral acceleration deemed to be "comfortable". The reader is directed to Section 5 for a discussion of the various modalities of curve-speed warning.

2.2 Key Requirements impinging upon the subsystem

2.2.1 Overview of Requirements

In order to meet the functional requirements for the CSW, we needed to customize a commercial land vehicle navigation system, designed with the robustness required to address the noise, vibration and temperature extremes to which the vehicles are subjected during the FOT data collection period. Commercial navigation systems are essentially self-contained systems comprising a GPS receiver, a speed sensor, and a yaw rate sensor for positioning, and a map database upon which navigation algorithms track the route taken. An internal processor provides the engine for the map access, mapping and user interface drivers to convey the route to the human operator. We have adapted a commercial system to meet the CSW subsystem requirements, as illustrated in Figure 2.2.1. In this design, the commercial Vehicle Positioning (VP) system calculates the vehicle position and locates the vehicle on the regional road system by augmenting the decoded satellite signal with Inertial Navigation System (INS) and commercial map database information. For the CSW application, the Look Ahead Module (LAM) within the Navigation Module (NM) extracts critical information on the road ahead of the vehicle. In addition to the vehicle's position on the map, extra information such as turn signal, yaw rate, and lane information are required to interpret driver intention and accurately identify the vehicle path ahead.
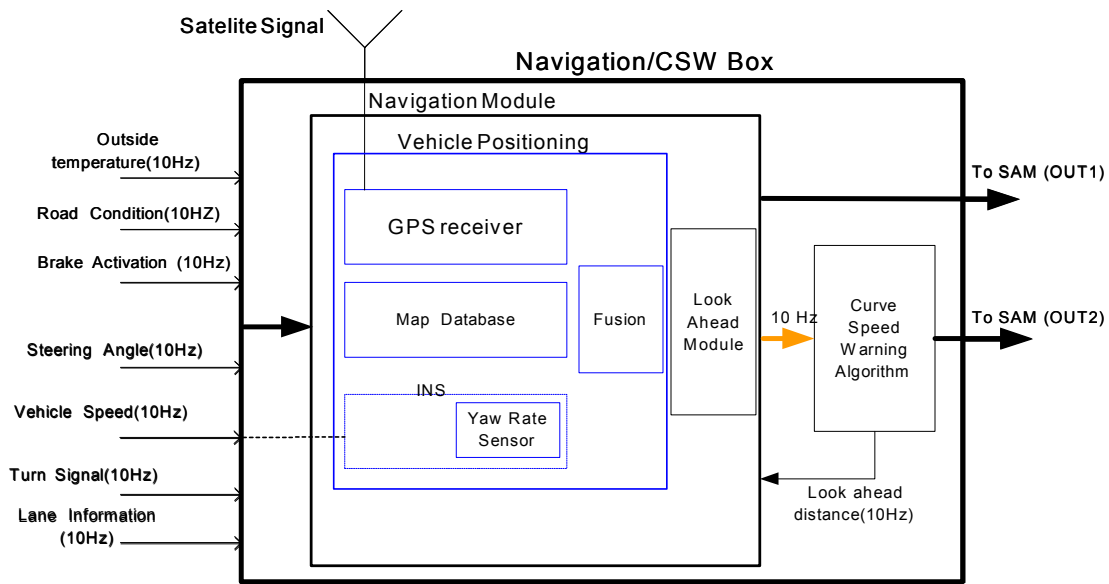
6

Figure 2.2.1 CSW System Block Diagram

2.2.2 Vehicle Placement

One of the key requirements for the CSW determination is the accurate placement of the vehicle within the road system. This task is complicated by data inaccuracies and timeliness of map data, GPS readings and yaw angle data. Indeed, the team clearly recognizes that discovery of map data constraints and management of their impacts on system performance are central aspects of this project's challenge. Within the selected navigation system hardware, the GPS data and yaw rates are provided only at fixed rates of 1Hz. Although we determined that the GPS update rate was sufficient, the yaw rate, along with the vehicle speed is needed to support dead reckoning that enables positioning of the vehicle in the absence of the more frequent GPS signal. For this reason, we established a criteria of yaw rate signal input to the CSW at 10Hz. This required an alternate gyroscope than the one packaged within the commercial navigation system. Details on this alternate hardware are provided in section 2.4.

In addition to the signals monitored within the navigation system, the CSW subsystem further refines the vehicle's position using information from other vehicle sensors. This allows for distinction between driving on a freeway or the freeway's service drive or exit ramp, or between other parallel or overlapping road sets within the driving region. Signals such as turn signal or proximity to an outer lane's boundary indicate to the system the driver's intention to move to an alternate road segment (parallel or intersecting), enabling better prediction of the path ahead of the vehicle. Other signals used for this purpose include:

- Accelerator Pedal Position

- Cruise Switch Setting
- Brake Switch Position
- Parking Gear Indicator
- Reverse Gear Indicator
- Turn Signal Indicator
- Front Wiper status
- External Temperature
- Left/Right Lane Boundary Types
- Lateral Velocity
- Vehicle Lateral Offset
- LDW Offset Confidence

Rather than install separate sensors for each of these signals, a requirement for a CAN bus within the vehicle from which these could be extracted was cascaded to the System requirements.

2.2.3. Curvature Data

A second challenging requirement for the CSW subsystem involved the availability of accurate curvature values for paths incorporating curves at radii of less than 1000 feet. This computation is not currently incorporated in any commercial products today, however, the so-called "spline fit" parameters that mathematically define such roadway curves are NAVTECH's research and development database known as ADAS Product Set One (APSO). This requirement was then expanded to two new requirements:

1. The region in which the FOT is to be conducted must be mapped at the APSO level of map data quality.

2. Efficient curvature computation techniques needed to be included in the CSW software.

To meet the first requirement, NAVTECH was contracted to deliver an APSO-level map database of the FOT region. Details on the efforts to meet the second requirement are covered in section 2.6

2.2.4 Threat Assessment

Given an understanding of the vehicle's path and the location/acuteness of approaching curves, the system is then required to determine the required response action of the vehicle to obtain a desired approach speed to enable negotiation of the curve that would keep the vehicle within its current lane. This involves monitoring the vehicle's acceleration/deceleration rates, current speed and the distance to the point on the curve with the lowest maximum negotiation speed. From these factors, the CSW system needs to assess the braking action required and establish a threat level correspondingly. This

information is conveyed to the DVI subsystem, which delivers the threat information, resulting in appropriate slowing of the vehicle. This threat assessment incorporates a model for driver response time as well, to compensate for delays in human response time to in-vehicle alerts.

2.3 Architectural placement of the subsystem

The CSW Subsystem's JoyRide platform will interface to the SAM via an RS232 serial connection. Details on this interface are provided in Appendix A.

2.4 Hardware provisions (component selection)

Due to the harsh vehicle environment and the toll this environment takes on sensitive electronic equipment, all hardware used to implement the CSW was designed for automotive applications. The Clarion JoyRide system meets this criteria and is the heart of the CSW system. In addition to meeting environmental requirements, the JoyRide platform includes all the necessary power management hardware to ensure correct operation to accessory cycles.
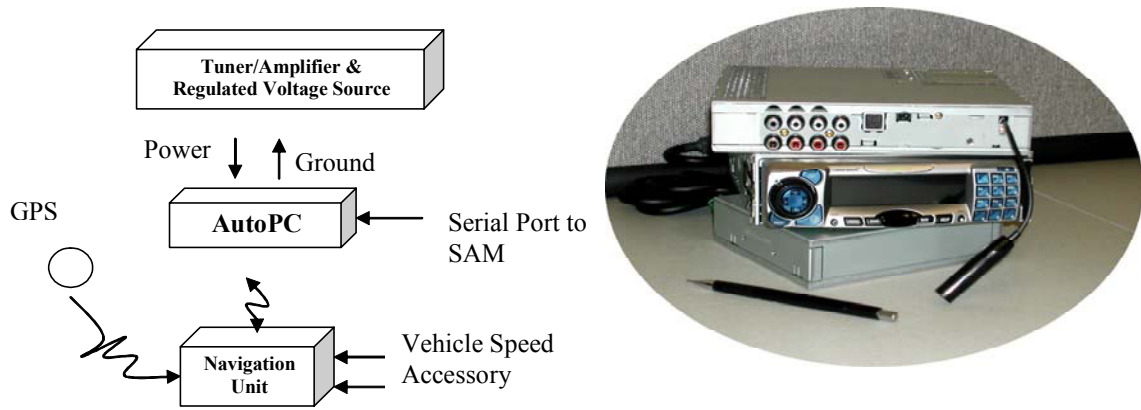

Figure 2.4.1 JoyRide Hardware Configuration and Photo

JoyRide System Specification

- Intel Pentium 166 MHz MMX

- 16MB ROM, 64MB RAM

- 256x64 Pixel, 8-color display

- WindowsCE 2.0 (minimal configuration)

- DVD-ROM, Compact Flash

- 2 USB ports, 1 RS232 port, 1 Compact Flash Slot

- Navigation Sensors: GPS Receiver, Gyro, Speed Pulse

- Operating Temperature Range: -10 degree C - +85 degree

- Yaw rate specification:

- Max angular velocity (°/S): ±300
    - Linearity (%FS): ±5
    - Response (Hz max): 50

- Physical Dimensions
    - Head Unit: 6"L x 7"W x 2"T
    - Black Box: 5 ¾ "L x 7"W x 1 ½ "T
    - Navigation Unit: 5"L x 5 ¾"W x 1 ½ "T

The JoyRide system is interfaced via a serial port to the SAM (SAM), which provides data from the LDW, external temperature sensor, Altima CAN bus and the alternate gyroscope. The alternate gyroscope was necessary to meet system requirements for a 10Hz update rate on the vehicle's yaw rate. The gyro chosen will be connected serially to the SAM, allowing the SAM to monitor and forward the yaw rate to the JoyRide system at the message communication rate of 10 Hz.

Figure 2.4.2 KVH Gyroscope Hardware

KVH E•Core 1000 Fiber Optic Gyro
- Model 2255140-1-3
- 10Hz
- RS232 Serial port
- Temperature compensated for both bias and scale

2.5 Software provisions

To meet the design requirements efficiently, the CSW subsystem required customization of an existing navigation application. To accomplish this, Visteon contracted with InfoGation Technologies, a division of BSQUARE. With InfoGation's extensive experience in designing and developing commercial navigation systems, and Visteon's engineering expertise in the area of path prediction and driver awareness systems, an effective CSW implementation team was in place to deliver the CSW

software. The CSW software implements the following process, using the terminology shown in Figure 2.5.1.

The vehicle position is located on the map by augmenting a decoded GPS satellite signal with inertial navigation system and map database information. Once the vehicle position is established, a look-ahead-module (LAM) extracts additional information about the road geometry that lies ahead.

The LAM predicts the most probable path and other possible alternate paths by using the vehicle's travel direction, the direction of the road, the vehicle lane, and the predicted directional change. Then, the LAM calculates confidence levels of the candidate paths based on a cost function and determines the most probable path of the vehicle by using information from vehicle positioning, lane information and lateral velocity (from the Lateral Drift Warning (LDW) subsystem), and vehicle state (e.g. outside temperature, brake activation, turn signal status, etc.). The cost function weights each parameter with respect to the consideration that the parameter will have toward predicting the vehicle's most probable path.

Once the most probable path is predicted, a look-ahead distance is determined. The look-ahead distance is the distance to the second branching point of the most probable path and has a maximum limit of 220 meters. A curve fitting technique is applied to the shape and node points contained within the map database to obtain a geometric representation of the path contained within the look-ahead distance. The look-ahead-distance is divided into 20 equally spaced points and a curvature calculation is performed to provide curvature values for each the points. Each curvature point has an associated curvature value, position value, a travel distance to the curvature point, an advisory speed, and the confidence value of the segment where the curvature point resides. This information is sent to the threat assessment module.

The threat assessment module selects the one of 20 points that has the maximum deceleration value required to achieve its respective advisory speed as the curvature point of interest. The generated threat level is a function of the deceleration required to get to the advisory speed at the curvature point of interest, the projected lateral acceleration at the curvature point of interest, the vehicle speed, the current deceleration of the vehicle and the driver reaction time. The threat level is modified based on the confidence level of the curvature point of interest.

The modified threat level along with the CSW sensitivity level selected by the driver [(low) 1-2-3-4-5 (high)] is used to determine when to issue a warning request and its severity level [i.e. ADVISORY, CAUTIONARY, or IMMINENT] for output to the DVI subsystem.

Distance To The Curvature Point

Turn Signals

Left Lateral Offset

Traffic Direction

Advisory Speed At The Curvature Point

Curvature Point

Look-Ahead Distance

Lane Boundary

Right Lateral Offset

Radius of Curvature At The Curvature Point

○ Node

● Shape Points

✕ Curvature Point [every minmum(LAD, next branching distance)/20]

↑ Vehicle Speed

●–▷ Lateral Velocity

∿ Yaw Rate

∨ GPS Antenna, (X,Y) GPS Coordinates

▼ Brake Pedal

▲ Acceleration Pedal

Every Curvature Point is associated with a curvature value, a distance value, a confidence value, and advisory speed value

Figure 2.5.1 Look Ahead Module Functional Elements

2.6 Performance issues

During this period, there were 2 significant performance issues that were addressed, both involving the data available to the CSW software from the supplied NAVTECH map data set.

2.6.1 NAVTECH DNDC and APSO Databases

The NAVTECH map data set is populated using specially equipped vehicles and trained drivers, driving the freeways, highways, urban and suburban road systems. Data is collected during the drives using a custom laptop application and a time-stamped voice recorder, and later collated into the NAVTECH proprietary Database for Navigation and Digital Cartography (DNDC). Selected sets of road data (e.g., all roads in Michigan) may then be extracted and compiled into Shared Data Access Libraries (SDAL) for use by navigation applications. The data collected by this system (in use since 1985) broke down the road systems into segments, with "nodes" defining the endpoints of each

segments, and "shape points" roughly defining the curved sections of segments. It was determined that the accuracy of the recorded GPS positions for the shape points, while roughly estimated the direction of the road, did not present enough detail on the shape of the curve or its radius at various points along the curve to meet the constraints of the CSW algorithms.

To get improved shape point accuracy and address the needs for the challenge detailed in section 2.6.2, we have subsequently selected to use the NAVTECH evaluation database developed to support NAVTECH Advanced Driver Assistance System (ADAS) programs. This database has been under development since 2000 and is known as ADAS APSO. This data set is a supplement to the DNDC data set and supplies more precise road shape information, meeting the CSW subsystem requirements. Further investigation revealed that the availability of APSO data for the Southeast Michigan region in which the RDCW FOT will be conducted was limited. To expand this coverage, NAVTECH has deployed additional resources to complete the APSO data collection for 7 counties within Southeast Michigan in order to meet the timing of the RDCW FOT Phase II.

2.6.2 Curvature Computations

The second significant challenge during 2002 addressed the need for curvature radius values for those road segments involving curves. In order to compute these radius values, several algorithms were explored, using the data from both DNDC and APSO data sets. Tradeoffs between the accuracy of the computations, availability of spline fit data and performance were taken into consideration to develop the curve fit algorithm. We have subsequently developed a formula that optimizes these and will produce the necessary accuracy for the curvature values. This curve fit computation has been incorporated into the CSW software and initial testing indicates a good map for the CSW algorithm's needs. This implementation will be tested and optimized further in the coming months.

2.7 Status of subsystem development

The CSW subsystem has completed both Alpha and Beta releases and is currently undergoing additional testing. The software has been developed to enable porting to a desktop simulation environment as well as the JoyRide platform. The desktop application has proved extremely useful during this debug phase since it:

- Enables replay of collected road data for analysis in the lab

- Permits inclusion of compiled Matlab models (DLLs) for segments of the subsystem software, enabling rapid experimentation of algorithm implementations

- Enables sharing of collected road data with Infogation (located in California)

- Enables demonstration of the CSW application

In addition to the software efforts, the JoyRide systems have been installed in the test vehicles and communication with the SAM is currently under test.

Efforts for 2003 include additional debug and refinement of the CSW application, followed by subsystem validation testing.

3.0 RADAR SUBSYSTEM
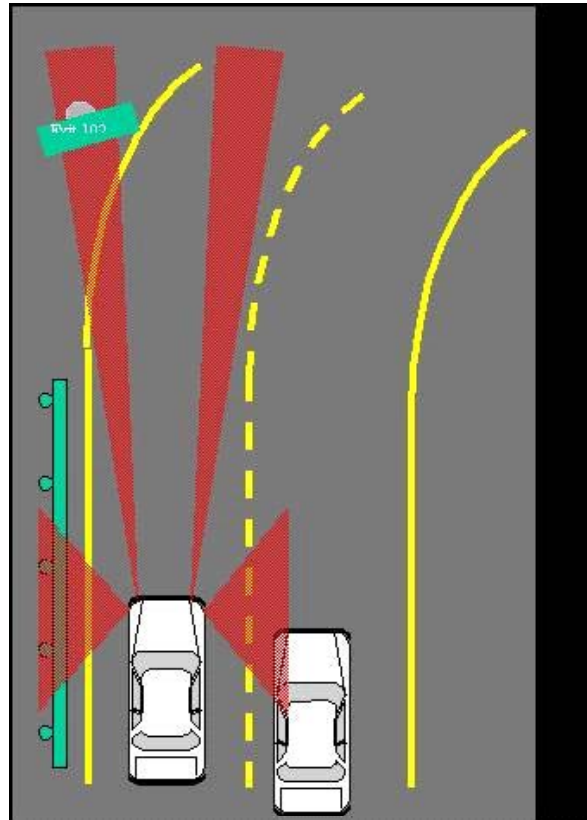
Figure 3.1.1 Radar Subsystem Coverage

3.1 Role of the subsystem in RDCW functionality

The primary objective of the Radar Subsystem is to provide other RDCW System components with information related to the current or projected (future) available (lateral) maneuverability room (AMR). The LDWS uses this available maneuverability room to modulate its warning threshold. A second objective of the Radar Subsystem is to provide information on roadside objects to be used by the look-aside map database. The radar subsystem utilizes two types of radar sensors to determine the AMR: 2 forward-looking radars, and 2 side-looking radars as illustrated in Figure 3.1.1.

The forward-looking radars communicate information to the SAM about the range and azimuth angle of forward objects like parked vehicles, roadside trees and bridge abutments. The SAM uses this data to calculate the lateral offset of each object from the projected lane and estimates the future AMR. The radars are able to detect objects at a range of approximately 30m to 60m in front of the vehicle. Seeing both the left and right roadside 30-60m ahead will require one forward-looking sensor to be mounted on each front corner of the host vehicle.

The side-looking radar sensors measure the lateral distance from the host vehicle to objects located directly adjacent to the vehicle including other vehicles on the roadway, guardrails, and other roadside structures. This information is used by the SAM to estimate current available maneuvering room to each side of the travel lane, as well as to refine the position and offset of objects detected by the forward radar(s) for subsequent designation as a "static" object and population into the look-aside database.

3.2 Key Requirements impinging upon the subsystem

The key requirement flowing down to the performance of the Radar Subsystem is the need to detect and accurately locate objects in the near vicinity of the host vehicle. Figure 3.2.1 illustrates side and front radar accuracy range. For the side-looking radars, this requirement is fairly simple in that it relates only to the range measurements made by these sensors. The side-looking radars are looking directly perpendicular to the vehicle's direction of travel and their range accuracy is within +/- 20 cm.

For the forward-looking radars, this requirement is more complex due to the need to estimate the lateral offset of each detected object. This means that the radar sensor must provide both accurate range and azimuth angle to each object. This requirement was fulfilled by employing a monopulse radar to determine azimuth angle to within +/- 0.3 degrees.
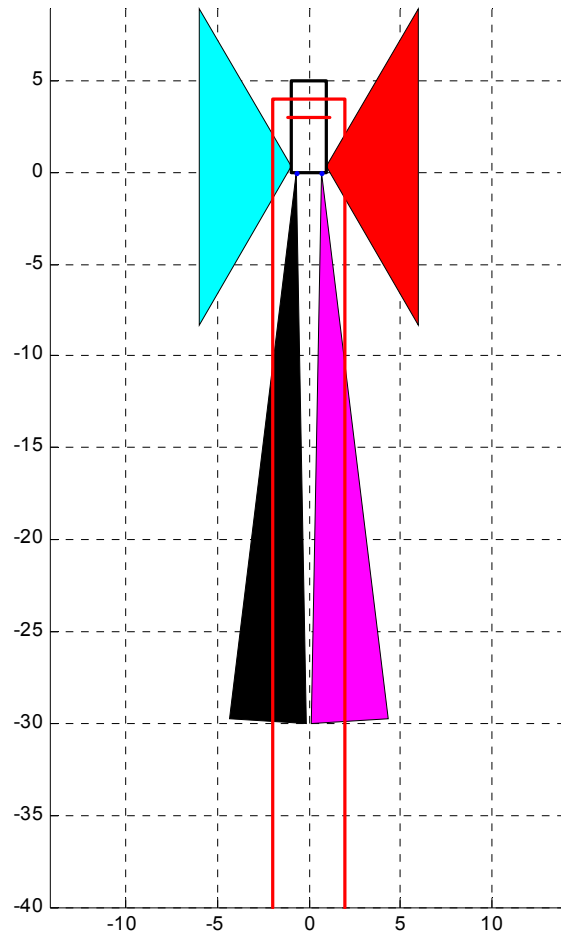
Figure 3.2.1 Radar Settings

3.3 Architectural placement of the subsystem

Figure 3.3.1 illustrates the placement of the four radar sensors on the host vehicle.

The side-looking radars are aligned so the boresight of each sensor is perpendicular to the vehicles direction of travel. The side-looking radars are physically attached to the front quarter-panel sheet metal as shown in the photograph below.

They are covered by the front fascia. The penetration characteristics of the side-looking radars allow it "see through" the fascia material.

The forward-looking sensors are placed at the front corners of the host vehicle. In order to get adequate coverage of the area adjacent to the lane of travel, each sensor

16

boresight is aligned 3 degrees to the outside of the vehicle. This provides adequate coverage to the side as well as to the front of the host vehicle. The sensors are mounted to a special bracket attached to the vehicle bumper structure. The front fascia has provisions for fog lamps (see figure), which have been utilized to provide an unobstructed view of the roadway for each forward looking sensor. The fog-lamp access holes have been covered with a piece of plexiglass (transparent to the radar energy) to protect the radars.

Figure 3.3.1 Radar Installation

3.4 Hardware provisions (component selection)

For the forward-looking radar components, the Radar Subsystem uses an adapted version of the Visteon 77 GHz radar developed primarily for adaptive cruise control and forward crash warning applications. The sensor is produced by AutoCruise and has the operating characteristics provided in the table below.

Feature	Performance
Maximum azimuth coverage	$\geq 8°$ at long range
	$\geq 11°$ at short range
Maximum elevation coverage (at - 3 dB)	$\geq 4°$
Polarisation	vertical
Maximum detection range, moving target (on motorbike, in straight lane)	$\geq 150m$
Maximum Detection range, fixed target (small vehicle)	Detection & location at $\geq 60m$
Maximum relative speed domain	± 250 kph
Distance measurement accuracy	Max ($\pm 1m$; $\pm 5\%$)
Angular measurement accuracy	$\leq \pm 0.3°$
Relative speed measurement accuracy	$\leq \pm 0.5$ km/h
Range bin width	3m
Speed bin width	0.15 kph
Maximum number of objects simultaneously tracked	30
Cycle rate	≈ 50 ms

Table 3.4.1 Hardware Provisions

For the side-looking radar components, the Radar Subsystem uses an adapted version of the Visteon 24 GHz radar developed primarily for Near Obstacle Detection Applications (e.g. blind-spot, back-up aid, etc.). The sensor is produced by M/ACom and has the operating characteristics provided in the table below.

Feature	Performance
Maximum azimuth coverage	120 degrees (10dB width)
Maximum elevation coverage (at - 3 dB)	17 degrees
Polarization	Horizontal
Maximum detection range (0 dBsm)	$\geq 10m$
Distance measurement accuracy	0.2 m
Angular measurement accuracy	None
Relative speed measurement accuracy	None
Range bin width	.2 m
Maximum number of objects simultaneously tracked	10
Cycle rate	≈ 30 ms

Table 3.4.2 Side Radar Details

3.5 Software provisions

The software provisions provided in this section deal primarily with the communications mechanism between the radar sensors and the SAM. Details of the SAM processing software for the radar data are provided in the SAM section of this document.

The figure below illustrates the bus architecture for the radar subsystem. There are two CAN buses, one allocated to the left-side sensors and one for the right-side sensors. Each bus is a two-wire, high-speed (500Kbps) CAN-based protocol. The communications mechanism for the long-range sensors will be a two-wire CAN-based protocol.

The two forward-looking sensors provide the following information for detected objects:

- Sensor Status (enabled, disabled, malfunction)

- Track Information (including track identification number)

- Range to object for specified track

- Range rate of object for specified track

- Azimuth to detected object for specified track

- Return amplitude of object for specified track

The two side-looking sensors provide the following information for detected objects:

- Range to object

- Return amplitude of object

3.6 Performance issues

Figure 3.6.1 illustrates the integration of the Radar Subsystem data into the overall RDCW System operation. The lines indicating the current and future available maneuvering room are a result of the data provided by the Radar Subsystem. Dynamic roadway tests have been very successful in terms of proving out the radar system functionality. Detailed validation testing procedures are in development and will take a more quantitative approach to the radar performance measurements.
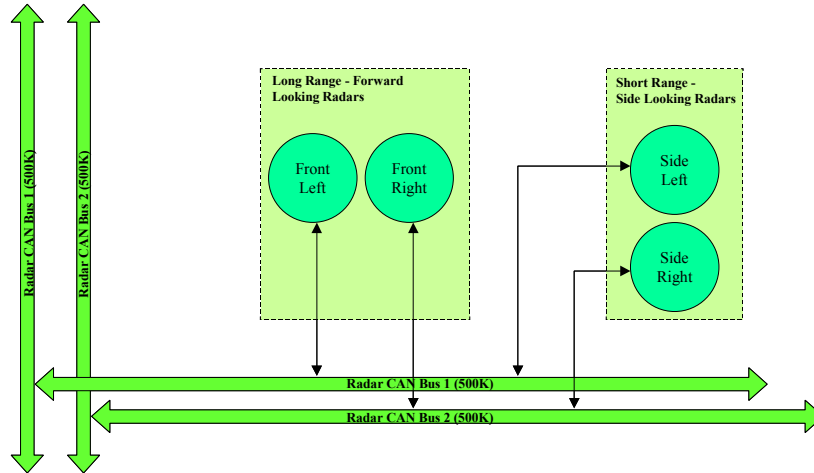
Figure 3.6.1 Radar Subsystem
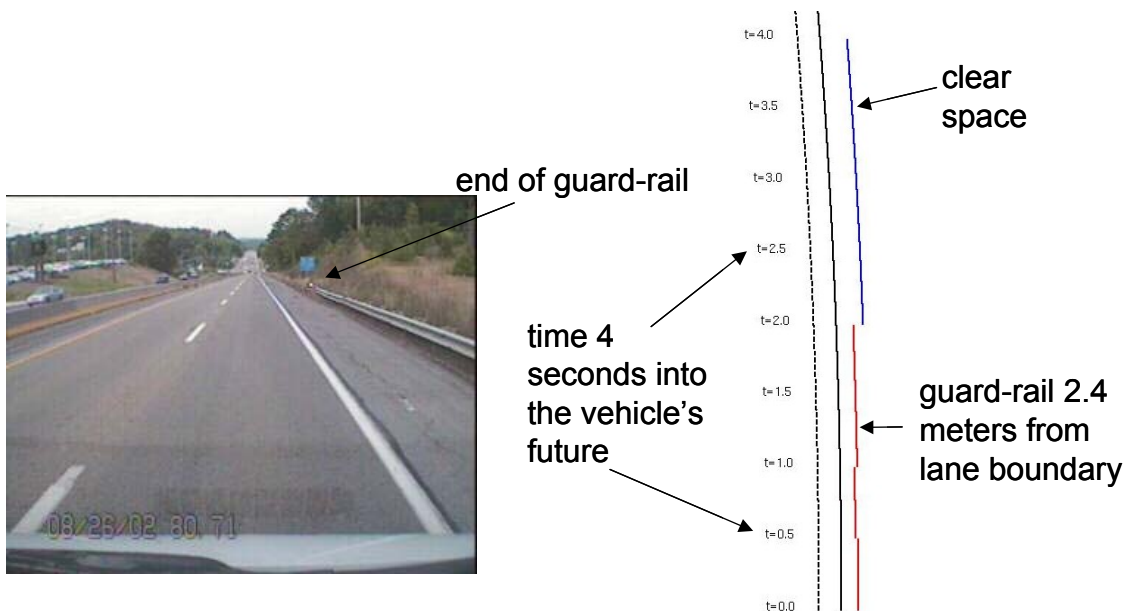
Figure 3.6.2 Lane Maneuvering

To date, the radar sensors have, for the most part performed, as expected. There has been one significant issue associated with the information provided by the forward-looking sensors. It has been observed that as objects near the azimuth extreme of the sensor FOV (e.g. 4 degrees off of bore-sight), the reported azimuth bearing becomes somewhat inaccurate. Observations have indicated that the errors result in objects being identified as being closer to the lane edge than they actually are. While this issue continues to be analyzed, the functional fix within the SAM is to ignore (i.e. filter) the object data when its reported azimuth angle nears the FOV extreme. This process has been implemented and has performed well under dynamic roadway conditions.

3.7 Status of subsystem development

The Radar Subsystem has been successfully installed on the first 3 prototype FOT vehicles. It has been successfully integrated with the SAM on the first 2 vehicles. The alignment procedure for the prototype vehicles has been specified and a more efficient procedure is under development for the remaining FOT vehicles.

The side-looking radar sensors have performed as expected and no changes are anticipated in the future. There has been one issue with the forward-looking radars (see above) that is still under investigation although it is not detrimental to RDCW operations. A second source for the forward-looking radar sensors is being evaluated at this time for a potential improvement in performance and mitigation of any delivery risks.

4.0 SAM SUBSYSTEM

4.1 Role of the subsystem in RDCW functionality

The SAM (SAM) plays two major roles in the RDCW system.

1) The SAM acts as a central repository and clearinghouse for all data that is produced by other RDCW subsystems. It receives data from one sensor or sub-system and sends it to the sub-system that needs the information. For example, lane boundary types (i.e. solid or dashed) are relayed by the SAM from the LDWS to the CSWS, vehicle signal status such as turn signals and brakes are relayed from the vehicle CAN bus to both the LDWS and CSWS, and all relevant information that the SAM receives will be relayed to the DAS.

By acting as an information relay, the SAM also monitors the health of each sensor and sub-system and reports that there is a failure if the SAM has not received data for some amount of time.

2) The SAM fuses all sensor information that it receives (GPS, gyro, radar, path information, vehicle information, lane information, and road information) into a single geometric description of the environment around the vehicle. By locating objects such as parked vehicles and guardrails relative to the travel lane of the vehicle, the SAM estimates the available lateral maneuvering room on either side of the vehicle. It sends this information to the LDWS in order for the LDWS to dynamically adjust its lateral drift warning thresholds.

The SAM also stores, in a database, relevant information to re-compute the available maneuvering room. This database, referred to as the Look-Aside Database, is used on subsequent traversals of the same road or highway. (Please note that, even during the brief exposure period of the FOT, most drivers will cover a substantial distance by means

of repeated transversals of certain road segments.) The database, in combination with the forward-looking radar sensors, allows the SAM to estimate the available lateral maneuvering room for 4 seconds in the future of the vehicle's travel (which translates to some distance in front of the vehicle depending on the vehicle's current speed).

4.2 Key Requirements impinging upon the subsystem

- Sufficient computing power to handle all sensor I/O and data fusion tasks.

- Sufficient storage resources to support the Look-Aside Database.

- Sufficient serial I/O for 3 serial devices (LDWS, CSWS, gyro).

- Sufficient I/O for 4 CAN channels (Left radars, right radars, vehicle bus, and RDCW system bus).

- Powered by 12-volt vehicle power.

- Ability to automatically start the software when vehicle ignition is turned on and safely shut down the software and CPU when ignition is turned off.

4.3 Architectural placement of the subsystem

The SAM is connected to all sensors and sub-systems in the RDCW system (reference Appendix A – RDCW System Architecture). It receives and transmits information to the LDW sub-system via a RS-232 serial link. It receives and transmits information to the CSW sub-system via a RS-232 serial link. It receives radar data from the left and right side CAN busses. It also sends vehicle speed information to each forward-looking radar sensor via the radar CAN busses. It receives information about the vehicle from the vehicle CAN bus. It receives information from a gyro sensor via a RS-232 serial link. It sends information to the DVI and DAS sub-systems via the RDCW CAN bus.

4.4 Hardware provisions (component selection)

The SAM hardware suite consists of 3 main components – a 333MHz embedded CPU with various common interfaces, two dual CAN network cards, and a multi-channel serial card. All of the cards are COTS products. Substantial engineering judgment played into our decision making process, however, this judgment was based on our prior use of each piece of hardware, and our confidence that it would suit the requirements of this research program. According to manufacturer specifications, every component in the SAM should be able to operate in the automotive domain.

4.5 Software provisions

The SAM software consists of a single executable with multiple processing threads. Each thread services a different sensor or sub-system. When data are received from a sensor, that sensor's thread handles the data appropriately. Currently, there are sensor threads to handle data from the CSW Subsystem, LDW Subsystem, left and right side-looking radars, left and right forward-looking radars, vehicle CAN bus, gyro sensor, and the RDCW system CAN bus.

Functionally, the SAM software consists of several different modules. A module can be thought of a specific function that does a certain task. For example, the heart of the SAM software is the data integration module, which fuses all sensor data into a cohesive geometric understanding of the environment around the vehicle. Each module registers for the sensor data that it needs to do its task. When the sensor thread processes that sensor data, each module that has requested the data is alerted that new data has arrived. The modules "wake up" and perform their intended functions. Modules can also be configured to "wake up" at fixed time intervals as well.

The following describes the different modules in more detail.

The Data Integration module is the core of the SAM software. It fuses all sensor data into a cohesive geometric understanding of the environment around the vehicle. When new sensor data arrives, say from the LDWS, the data integration module wakes up and updates its model of the environment. This module computes the following from the raw sensor data:

- Determination of travel lane using lane boundary types from the LDWS and road type from the CSWS ADAS database.

- Location of objects sensed by the radar relative to the edge of the lane. The SAM uses the ranges, azimuth angles and amplitudes from all four radar sensors, the vehicle's lateral offset in the lane from the LDWS, and the road curvature and coordinates of the most likely path from the CSWS.

- Global vehicle position using the GPS information from the CSWS, gyro and vehicle speed from the vehicle CAN bus. The SAM requires this data to store and retrieve information from the Look-Aside Database.

- Finally, the data integration module uses the above three pieces of derived information along with the estimated shoulder widths from the LDWS and retrieved information from the Look-Aside Database (if available) to compute the combined available lateral maneuvering room on either side of the vehicle's travel lane.

The Data Output module wakes up at a fixed time interval (20 times per second) and transmits the required information to the LDWS, CSWS, DVI and DAS sub-systems.

The Logging module requests all sensor data and logs it to a file, which can be analyzed later in the lab.

The Remote Interface module handles the connection to the Graphical User Interface shown below. The Graphical User Interface connects to the SAM computing box via an Ethernet cable and allows the user to monitor various internal SAM variables as well as provides a graphical representation of SAM's sensor fusion.
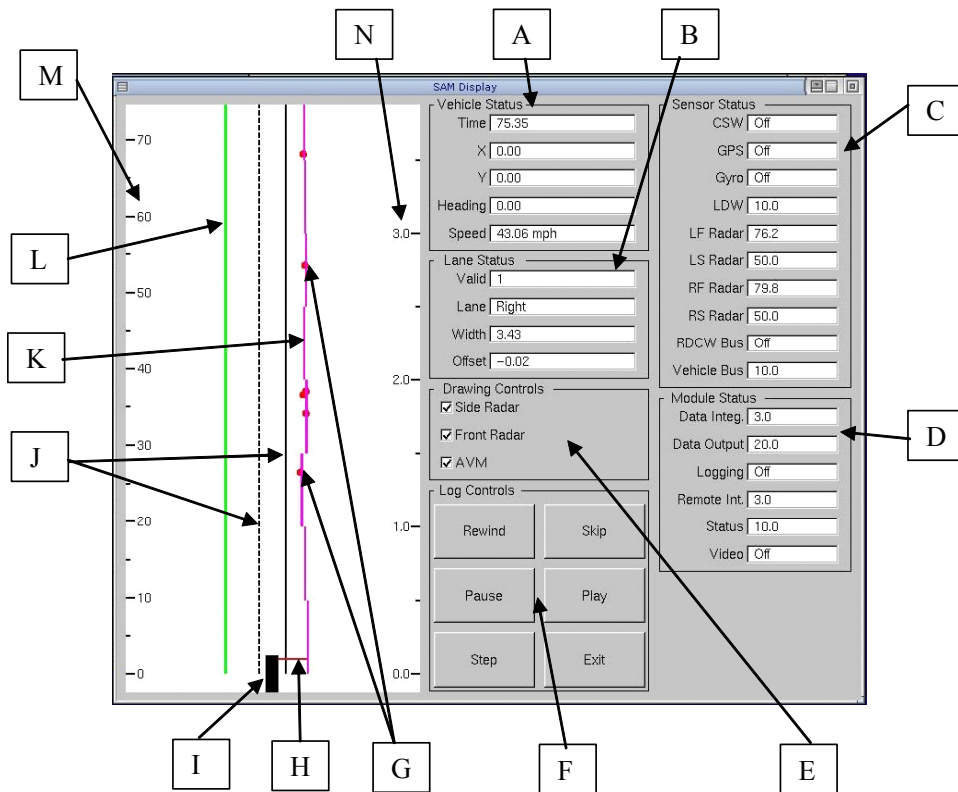
Figure 4.5.1 SAM Graphical Display Tool

Key:

A) Internal SAM time stamp, vehicle location, heading and speed.

B) Lane information including lateral offset and lane width.

C) Sensor and sub-system input status and health.

D) Internal SAM functional status and health.

E) User controls for toggling the display of side radar, forward radar, and available maneuvering room information.

F) Log file controls.

G) Forward radar target locations

H) Side radar range information.

I) Nissan prototype test vehicle.

J) Lane boundary types from the LDWS.

K) Right side available maneuvering room. In an actual case a magenta color means there is an obstacle within 4 meters from the edge of the right lane marker; otherwise a green color indicates an absence of obstacles.

L) Left side available maneuvering room. In this case, the green color indicates the left side is clear (i.e. no objects within 4 meters of the left lane marker).

M) Look-ahead distance information, in meters.

N) Look-ahead time information, in seconds. This always stays at a constant 4 second look-ahead time.

The Status module wakes up at a fixed time interval (10 times per second) and monitors the health of all sensors and sub-systems that send information to SAM.

4.6 Performance issues

There are two main issues concerning the performance of the SAM module.

1) With the massive amount of sensor data flowing into the SAM module, the software had to be designed to handle communications while still providing computing cycles for the data integration module of SAM. This is achieved with a number of strategies from using built-in interrupts on the serial line to avoid constantly polling, to ignoring much of the data from the side radar sensors, to sub-sampling the data from the vehicle CAN bus. We have found sufficient processing power to handle not only the data integration portion of SAM but also the various support modules such as Logging and the connection to the Graphical User Interface.

2) For optimal functioning of the SAM module, it requires accurate data from all incoming sub-systems and sensors. In the face of poor data, or no data at all, however serves to provide a reasonable estimate of roadway geometry even when much of the sensory data is missing. the SAM should not simply quit working. By using assumptions, the SAM module degrades gracefully to still deliver meaningful data. For example, consider the case of a newly traveled road where the LDWS is having difficulty estimating the available shoulder width. The SAM can still provide information about the available lateral maneuvering room by using "instantaneous" radar data. The SAM software has been designed with this type of functionality in mind.

4.7 Status of subsystem development

All four SAM computing hardware boxes have been constructed and tested for the four prototype vehicles in Phase I. A fifth SAM computing box exists for in-lab testing. The SAM software has been installed and tested on three prototype vehicles.

All software I/O to all RDCW subsystems is complete and tested with the exception of the CSWS, DVI, and DAS sub-systems. The interface between the SAM and CSWS has been implemented but is untested as of this time.

All health-monitoring functions of the SAM have been tested with the available RDCW Subsystems.

All major data integration algorithms are complete and tested. The last major piece that requires integration is information from the CSWS. In the interim, we have used a secondary GPS and gyro sensor to test those portions of the CSWS input message.

Overall, the SAM hardware and software remains on schedule and is working well.

5.0 DRIVER VEHICLE INTERFACE SUBSYSTEM

5. 1 Role of the Subsystem in RDCW functionality

The Driver Vehicle Interface Subsystem will provide the driver with a unified, consistent interface to the roadway departure countermeasure. Its first role will be to arbitrate between road departure warning signals and curve speed warning signals based on the severity of each threat, to avoid driver overload and/or confusion. It will also support the driver vehicle interface display, which will include status information during times of low road departure danger, as well as urgent warnings of an imminent road departure. The DVI will also control the vehicle's audio system by adjusting the volume from the radio commensurate with the ambient noise level to ensure that the warning is always audible to the driver. As part of the warning implementation, the DVI may also provide a haptic component to the imminent level warnings. Furthermore, the driver will be able to adjust the sensitivity level of both the CSW and LDW Subsystems to modify when the cautionary and imminent warnings are actually given to the driver, in relation to the CSW or LDW event.

5.2 Key Requirements impinging upon the system

The key requirement of the DVI is that it provides a safe and effective means of interaction between the driver and the RDCW systems. The following are the general guidelines that apply to the DVI sub-system:

Condition	DVI equipment	Applicable Standard
Dust	All	SAE J1455 4.7.3
Fungus	All	MIL-STD 810
Mechanical shock	Wiring harness	SAE J1455 4.10
Thermal Shock	All	Function during cycles of –20 to 80 degrees C
EMI	All	Accelerated Stress Assurance plan 2.3 EMC-RF
Human Factors	Interfaces	MIL-STD-1472D
Human Factors	DVI Controller	SAE J2395 Messaging Priorities
Human Factors	DVI Controller	ISO 16951 Messaging Priorities

Table 5.2.1 DVI Requirements

There are also RDCWS application specific requirements. These are as follows:

Imposing component or sub-system	DVI equipment	Requirement
Other systems		
Vehicle power	All sub-systems	Usual automotive voltage and current constraints
Vehicle CAN bus	DVI Controller	Altima CAN messaging requirements
Data CAN bus	DVI Controller	RDCW Data CAN messaging requirements
SAM, DAS	DVI Controller	10 Hz update rate
DVI sub-system		
Haptic Controller	DVI Controller	ASCII messages @ 33.6 KBaud, 1, 8, none
Engineering	DVI Controller	Discrete inputs (sensitivity switches) via DIO
Engineering	DVI Controller	Discrete inputs (tell tale inputs) via CAN
TCS & Dimmer	DVI Controller	TCS & Dimmer switches will be repositioned
DVI Engineering		
Engineering	DVI Controller	Maximum 100 mSec processing lag
Engineering	DVI Controller	Warnings will not be pre-empted nor escalated.
Engineering	DVI Controller	Haptic warnings will be composed of a single pattern
Engineering	DVI Controller	Muting level calculated via algorithm (no user input)

Table 5.2.2 DVI Application Requirements

RDCW functional requirements ensure that the system can support a broad array of DVI-delivered messages and forms of alert. Of course, driver workload considerations suggest that only the necessary and sufficient set of these capabilities is actually employed.

The system is designed to meet the following requirements:

- The driver shall not be able to disengage the RDCW System.

- The DVI module shall issue system state messages including RDCW System Unavailable, CSW sensitivity level, LDW sensitivity level, RDCW Service Required, LDWS self-service, LDW Unavailable (with Left/Right distinction) and CSW Unavailable.

- The DVI shall issue warnings based on the threat level. The warnings are advisory, cautionary and imminent.

- Warnings may be combinatorial and may include audio, visual and haptic components.

- All visual components (icons and graphics) shall be unique.

- All auditory components (warning tones) shall be unique.

- All auditory components shall be audible over ambient noise levels, including wind, road and entertainment system noise, without being startling to the driver.

- All warnings shall be easily discernable by the driver with minimal training.

5.3 Architectural placement of the subsystem

The DVI interfaces with the RDCW system via the RDCW System CAN bus (reference Appendix A – RDCW System Architecture). It interfaces with the driver through the CSW and LDW Sensitivity switches, the Nissan Altima audio system and haptic feedback in the seats. The DVI module controls the Driver Display through a panel link connection. It employs serial RS-232 communications protocol to control both the Haptic Controller and the Custom Audio Interface Module (Audio Matrix Switch).

5.4 Hardware provisions (component selection)

The following diagram shows the DVI architecture and the various component subsystems that make up the DVI Subsystem. Each of these component subsystems is described in the following sections.
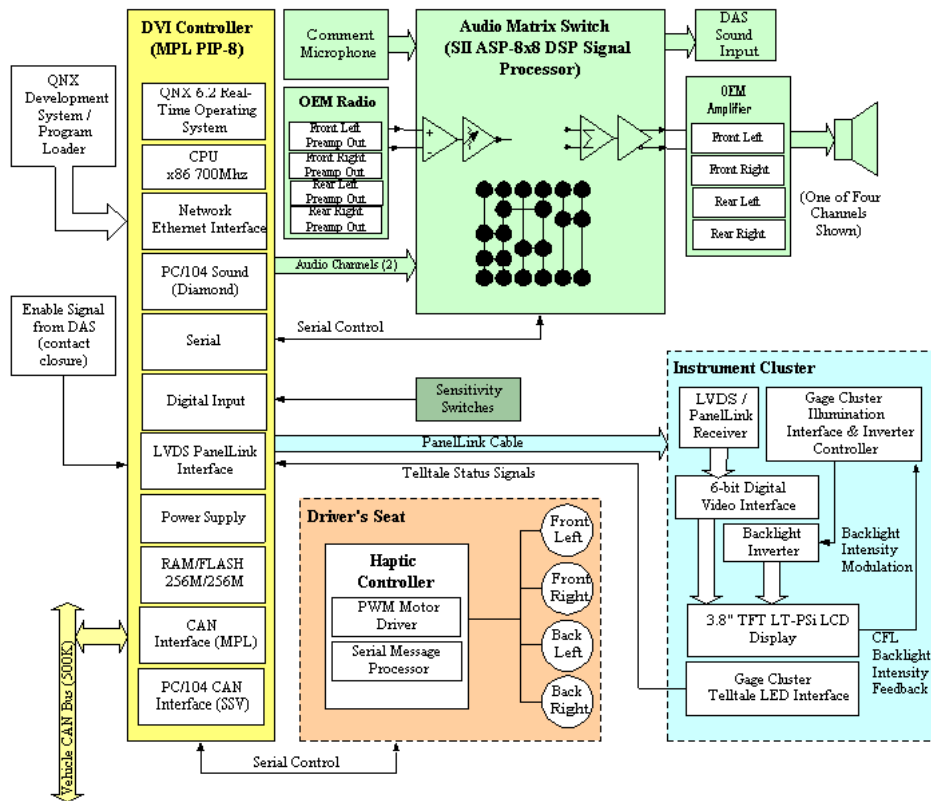
Figure 5.4.1 DVI Subsystem Architecture

5.4.1 DVI Controller

The DVI Controller (shown on the left in figure 5.4.1) interfaces to the Nissan Altima CAN bus, through which it communicates with the SAM. This controller incorporates the arbitration and device driver software, managing which signaling hardware is activated based on the CSW and LDW requests for alert. In addition, the DVI monitors the health of the RDCW system as well as several other Altima system statuses (e.g., Wiper Fluid Low, Service Engine and Door Ajar), managing the display of these statuses through the video display.

The MPL system was selected for this application for its low power consumption and its ability to meet the requirements for interfacing efficiently with the multiple driver interface modules as well as with the vehicle's CAN bus through which this controller will communicate with the SAM and DAS modules.   An additional benefit is its efficient Low Voltage Differential Signaling (LVDS) PanelLink interface and display drivers to permit driving the instrument cluster display unit across the lengthy 4.5m distance between the trunk area and the dashboard. Expandable ports in this controller will permit installation of a Diamond Audio sound card, used to generate the auditory signals. Development is also facilitated by the ability to upload files via CD or floppy to internal

hard disks, with subsequent transfer of the DVI software for the Phase II test vehicles in reliable, fast FLASH memory, eliminating the need for hard disks in the final vehicles.

Figure 5.4.2 DVI Controller

MPL DVI Controller
- Low Power 700Mhz Pentium III
- 256M SDRAM
- 2 port PC/104 Plus Interfaces
- 3 bus CAN interface
- 4 RS-232, 2USB & 1 parallel port
- 10/100 Mbit/s Ethernet
- SCSI-2 port
- Low Voltage Differential Signaling (LVDS)
- Integrated SXGA Controller
- QNX Operating System (V6.2)

5.4.2 Audio Components

In order to implement a sound system to produce the RDCW signals, we will broadcast using the Altima's factory-installed speaker system by incorporating an intermediary control circuit between the vehicle's radio and amplifier modules (as illustrated in Figure 5.4.3). This will consist of an 8x8 DSP-based Audio Matrix switch, which will accept 4 entertainment system inputs, a unidirectional microphone (to monitor ambient noise levels) and 2 wav player inputs (from the DVI controller). The switch will output to the Altima's amplifier the appropriate audio signal, either music or the RDCW tone or a combination of these. A separate switch output will route the microphone signal to the DAS for data collection.
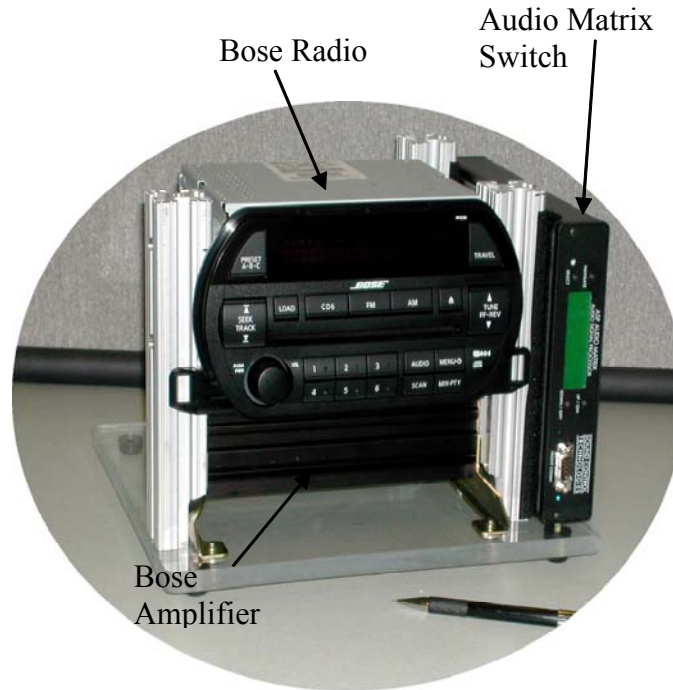
Figure 5.4.3 Audio Components

Audio Matrix Switch
- DSP Based crosspoint switch
- Programmable mix levels
- VU measurement of Radio and Ambient Levels
- Serial Control

5.4.3 Driver Display

The video display module design reuses a 3.8" TFT display (QVGA 320x240) currently in production within Visteon for other automotive navigation products. An additional controllable backlight circuit board and an inverter board supplement this display hardware to ensure visibility under all lighting conditions. The backlight circuitry will be interfaced directly to the vehicle's dimming switch so that the display's intensity can be varied to match the illumination intensity of the production instrument cluster. The TFT display will be positioned in the existing instrument panel cluster, replacing the area previously occupied by the Tachometer and several telltales. This requires reconstruction of the instrument cluster in this region, trimming the plastic housing and creating a new fascia to mask the display housing.

The visible display screen will be constructed of 4 layers of bitmap images as illustrated below.
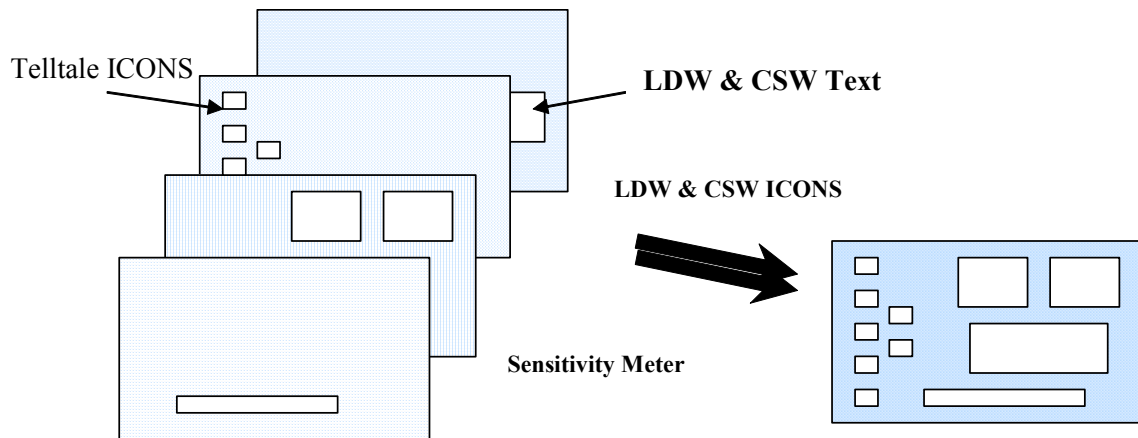
Figure 5.4.4 Visual Display Construction Concept

There will be 4 layers of bitmap images. The first layer contains the graphic indicating the driver's selected setting for the sensitivity meter. The second layer reveals the icons for the LDW and CSW alerts, cautions and warnings. These icons are defined by the Human Factors Icon Study, detailed in section 5.7. Created with Adobe Illustrator, these icons will be stored as bitmaps to simplify retrieval for display.

The third layer displays the telltale icons for the vehicle state. These telltales in a production Altima are hardwired into the tachometer area but, due to the installation of the display, must be redesigned as bitmaps for display in the TFT screen. The fourth and final layer contains any text that is required for the RDCW system and its subsystems. Within these layers, each pixel will consist of a defined RGB value. These defined RGB values are optimized for this prioritized layered display resulting in derived coloring for each pixel in the final screen. Updates to portions of the screen will be facilitated with this layering, enabling fast updates for RDCW information to be displayed.

5.4.4 Sensitivity Switches

In order to provide the driver with some ability to adjust the alerts in accordance with driving style, the RDCW system incorporates 2 sensitivity switches, for LDW and CSW respectively. The selected Marquardt switches provide momentary actuation in 2 single-pole switches, packaged in a single part. Backlighting will be provided to allow for night visibility.

5.4.5 Haptic Components

The haptic module will integrate a controller relay board, permitting activation of up to 8 direct current offset weight motors. This module will be installed within each driver's seat such that no hardware will be visible or detectable to the seated driver. A metal housing will surround the motors with a flat section of metal welded to the top to avoid any shifting of the motors in the protrusion of the seat. The components will then

32

be sandwiched between rigid metal sheeting and transparent plastic sheeting (top), and subsequently bolted to the seat frame. Human factors testing will be used to determine if 4, 6 or 8 motors are required to signal the driver. Using the maximum of 8 motors as an example, 4 motors will be located in the seat bolsters, 2 each to left and right, and an additional 4 motors will be installed in the seat back bolsters to the left and right. This is illustrated in Figure 5.4.5. below.

Figure 5.4.5 Haptic Seat – Transducer Distribution

InSeat Solution haptic system

- 8 transducers; four in seat bottom, four in seat back
- Serial interface card
- Each transducer independently programmable for:
    - Voltage 12-20V
    - Duty cycle 0-99 of PWM signal at 18 ms period
    - Pulse duration of 18 ms to 3 minutes

5.4.6 Ambient Microphone

A custom silicon-based microphone and circuit board will be installed in the vehicle to enable monitoring of ambient noise volumes for adjustment of the RDCW tone outputs.

5.5 Software Provisions

The DVI software consists of several multi-threaded processes to provide for:
    - Interaction with CAN and serial communication ports

- Interaction with audio and display interfaces
- Alert selection based on feedback from the CSW and LDW subsystems
- Alert arbitration between CSW and LDW feedback
- Alert signal (visual, auditor and haptic) identification and generation

First, these processes will establish the priority of the messages received, determine sensitivity settings, and monitor state information on the alerts and RDCW system status. This evaluation will enable the state transition logic to interpret the state information and issue the appropriate visual, auditory and haptic responses to the hardware driver processes. The hardware drivers then generate the various graphic display layers on the LCE, control the audio output through the matrix switch interface and drive the haptic serial controller hardware.

All of these processes and state transition logic are being captured within Matlab models. In addition, auto-code generation is used to generate an executable file that is downloaded to the QNX-based rapid prototype development system distributed by Opal RT. This test technique will be used to verify the DVI software implementation, incorporating the advance debugging capabilities of this hardware-in-the-loop platform. Once the model is verified using these simulation tools, it is converted to C source code using Matlab's Real Time Workshop tool. The C code is then ported to the X86 DVI controller via the Momentics development environment in QNX. Autocode generation is exploited to assure consistency between the simulation model execution and the target model.

5.6 Performance Issues

The DVI Subsystem design involved significant effort in identifying the many disparate components required to build the 3 modalities into the Altima. The more significant of these efforts involved the selection of an LCD display in which the visual images would be provided to the driver. The volume of visual signals to the driver (over 15 separate signals) drove us to implement an LCD display over discrete icons within the instrument cluster. We identified the Tachometer region of the Altima's instrument cluster as the optimal location for this display, defining our size for the panel. Additional environmental and display boot requirements also limited our selection, resulting in our selection of the 3.8" TFT display described in section 5.4.3. Other components were also selected for robust match to the automotive environment. Testing on these separate modality components continue and have not revealed any issues at this point.

5.7 Status of Subsystem Development

We have made progress in 6 specific areas of the DVI Subsystem. These include:

1. Completed construction and installation of haptic systems for 4 test vehicles and the UMTRI simulator. Numerous haptic transducer activation patterns were identified for testing, an undetermined subset of which will be tested in the UMTRI simulator. Pilot testing has been completed for this experiment, which will be executed using 16 subjects. The current strategy is to only present haptic signals for imminent warnings, and to use specific transducers for LDW to the right, LDW to the left and CSW. Each subset will be unique and directional.

2. Prepared UMTRI simulator for haptic human factor studies, including selection of haptic signals for evaluation.

3. Completed execution of planned icon matching human factors test for RDCW alerts. The icon matching test is meant to determine whether similar icons may be confusing or ambiguous to drivers. One hundred twenty participants were recruited from customers at the Ann Arbor and Ypsilanti offices of the Secretary of State (the Michigan driver's licensing bureau). Participants were presented with a written RDCW function and matrix of icons. Only the warning functions are tested, as additional testing on the system state messages needs to be completed. However, we did test two options for both the lateral drift and the curve speed warning systems. The participants were asked to match the function with the icon that was most appropriate. Each participant was asked to provide a match for only one of the RDCW functions. Table 5.7.1 indicates the percentage of participants correctly identifying the target icons.

Icon Options				% Correct
LDW 1	Advisory	Cautionary	Imminent	63.33
LDW 2	Advisory	Cautionary	Imminent	60
CSW 1	Advisory	Cautionary	Imminent	77
CSW2	Advisory	Cautionary	Imminent	63.3

Table 5.7.1 Icons Summary

4. Completed selection of auditory signals and execution of auditory human factor studies for RDCW alerts. The first of the DVI characteristics studies was run in the UMTRI simulator, a fixed-based GlobalSim Vection, which had been outfitted with the Bose audio speaker system from the Nissan Altima. The study examined a suite of auditory warnings being considered for both of the RDCW subsystems. The characteristics of the tones examined differed for the two subsystems. The signals examined for cautionary and imminent levels of warning in the LDW subsystem included earcons (rumble strips) and abstract tones. For the CSW subsystem, the signals examined included verbal commands (e.g., "brake") and abstract tones. The use of localized presentation of auditory warnings (i.e., presenting signals out of speakers in the direction of the hazard) was also examined for the LDW subsystem. The data collected included response times to the onset of the candidate signals, as observed through a variety of driver inputs (steer angle, brake pedal actuation and throttle release). Analyses of the data from this study are continuing into first quarter of 2003.

5. Progressed on several hardware development tasks

   a. Took delivery and began testing with DVI controller and video driver. Additional custom display hardware is also under development to provide for backlight dimming to match the behavior of the other instrument lighting, and to accommodate cold startups in which additional current must be provided to the display to ensure visibility until normal operating temperatures are attained.

   b. Began testing of audio mixing hardware, integrated with the Altima's BOSE system. This system allows for the dynamic measurement and control of both pass-through and mixed audio signals sourced from the DVI controller's audio output.

   c. Finalized switch selection and location. The Marquardt switches were selected for sensitivity adjustments. These switches will be repainted to create a custom mask. This mask will incorporate backlit graphics and text to clearly delineate the switch functions for the CSW sensitivity or the LDW sensitivity adjustment.

6. Drafted the DVI Requirements, Design Specification and FMEA. Further developed the DVI software states and their transitions, and documented these in a Matlab model.

Subsequent work will incorporate the results of the Human Factors studies into the DVI implementation. In addition, the complete DVI Subsystem will be constructed

within a test vehicle, permitting in-vehicle testing of the DVI Subsystem and it's processing of the data from the other RDCW subsystems.

6.0 DATA ACQUISITION SUBSYSTEM

6.1 Role of the DAS subsystem in RDCW functionality

The Data Acquisition System (DAS) is basically a silent, passive element within the RDCW FOT test vehicle. That is, it does not participate in determining the RDCW functionality that is experienced by the driver, except in the context of a very basic "enablement" function. When a test subject first receives an RDCW vehicle, the DAS is configured to disable the DVI subsystem so that the driver perceives only the baseline behavior of the Nissan Altima sedan. Throughout this baseline period, the DAS collects all of the same data as it will later when the warning interface functions are present to the driver. At a date that is nominally six days after the start of the subject's assignment, the DAS controls the switchover from baseline to RDCW functionality. In this sense, the DAS determines the gross functional state of the test vehicle—i.e., baseline vs. RDCW— in no other way is the presence of the DAS perceivable by the driver.

The role of the DAS is obviously to collect data. It performs this role in one of three high-level modes of operation, as follows:

1) At each ignition-ON event, the DAS boots up and executes its data collection and on-line processing functions as needed to support both of the later modes, (2) and (3);

2) At the ignition-OFF event, the DAS performs its end-of-trip computations and compiles a set of trip-summary statistics. It establishes via cell-modem a wireless connection with a data server in the UMTRI building and uploads the packet of trip-summary data. Modes (1) and (2) take place in conjunction with each trip sequence, such that all of the FOT data assume a high-level structure that includes trip numbering and a clustering of the data by trip.

3) When a hardwire connection is made with an ethernet port on the DAS, upon the return of the vehicle to UMTRI, a data transfer protocol is employed for offloading the full content of the data from the DAS hard disk. Once receipt of the data has been fully confirmed within the UMTRI server, erasure of the DAS hard disk memory is authorized.

The DAS also has manual interaction modes by which new code can be downloaded and some elements can be manually entered such as when identifying each new driver and when revising the metadata which serve to document the DAS software configuration and each of the data channels that are being gathered.

6.2 Key Requirements impinging upon the subsystem

Several requirements bear upon the design of the DAS, as contained within the System Requirements document and as established by the UMTRI infrastructure for data monitoring and archiving. Highlights of these requirements are as follows:

1) federal requirements – the DAS is designed to yield a dataset that meets the needs of both the RDCW Team and the Volpe Center. This requirement is satisfied through a negotiation process by which the desired datalist is identified, together with the sampling attributes of each data element. A current version of this datalist is presented in section 6.6 of this Interim Report.

2) Main module – the DAS module is required to satisfy the physical constraints of the trunk installation space, and the thermal, power, and EMI constraints that make it compatible with the RDCW platform.

3) RDCW System interface – The DAS reads data passively from RDCW CAN buses, per the requirements of the CAN protocol. The DAS also connects to the DVI module of the RDCW system to effect the switchover from the baseline configuration to the RDCW-enabled portion of the driver's assignment.

4) Ancillary elements – the DAS is also responsible for directly supporting several ancillary transducers and antennas that exist only for the sake of data collection. That is, these items do not contribute to the RDCW functionality, but rather are included for the generation (and transmission) of data. These elements are identified in section 6.3 of this document.

5) Database requirements – the bulk of the DAS software as well as its data formatting and communications protocols are determined by the UMTRI infrastucture for database compilation and management. The DAS serves basically as a mobile appendage to this infrastructure.

6) Mechanical requirements – While the DAS is designed to perform reliability under the vibration, thermal, and humidity demands of the automotive environment, it is not required to perform under crash levels of loading.

7) Serviceability requirements – The DAS is designed as a module of replaceable elements. The DAS package is further designed to quickly fold open to allow full access for the replacement of such elements. Diagnostic connections also provide for troubleshooting as part of the serviceability objective.

6.3 Architectural placement of the system

Figure 6.1 shows the data acquisition system (DAS) in relation to other RDCW components. The DAS utilizes two major sources of data: data buses and "FOT sensors,"

which are sensors installed solely for FOT data collection. FOT sensors are not used in the crash warning functionality. The FOT sensor set is shown in the figure, and includes: forward scene camera, driver face camera, driver voice microphone, comment button, steering wheel angle sensor, three-axis accelerometer, RF sensor (for detecting cell phone use), and differential GPS. The DAS uses vehicle power and ignition signals, although it has a backup battery and dedicated power management processor. The DAS will access the main RDCW project CAN bus (also shared by the SAM and DVI units). There is a possibility the DAS may need to access the Nissan vehicle CAN bus; direct access of the radar buses may also be required. Decisions on these CAN bus connections will be made soon.

The DAS provides two outputs during operation of the vehicle by FOT subjects. The first is a hardwire signal that will indicate to the RDCW's DVI processor whether the crash warning function should be displayed to the driver. This is done to support the FOT experimental design whereby the FOT driver first uses the test vehicle without the functionality for some period of time (the "baseline" driving period), and then the function automatically enables at some pre-determined time. The DAS also outputs a cell modem output (phone call) to transfer a summary of data at the end of each driver trip.

The main DAS module will consist of several elements, including two main processors connected by Ethernet, and a third power management microprocessor. The main processors include an audio-video data collection unit that is slaved to the primary processor. The primary processor accesses the CAN data buses and all FOT sensors, except the audio and video sensors. Several cards and supporting hardware systems are included within the main DAS module.
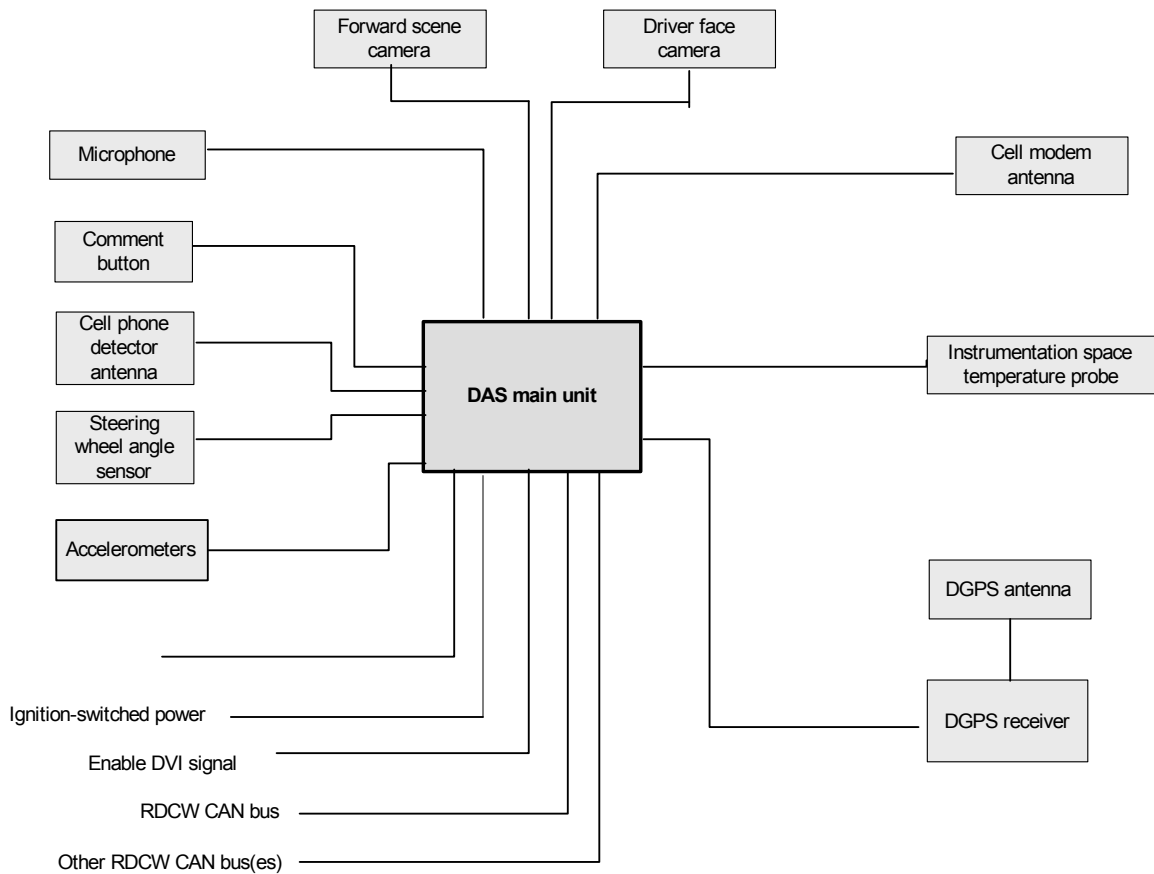
Figure 6.1 Data acquisition system – schematic of inputs and outputs

6.4 Hardware provisions

Hardware for the main DAS module is not finalized, however it will borrow heavily from the mature design of the ACAS FOT program. This uses two EBX format processors (Pentium II) and a Blue Earth microprocessor for power management. Military spec ruggedized hard disks (30 GB) are used for data storage onboard the vehicle. These include thermostats and heating for low-temperature use. UMTRI has run these units successfully for several thousand miles at temperatures between -9 and 95 F. These items are being re-evaluated for the scope and needs of the RDCW FOT project.

Table 6.1 below shows the hardware component selections made to date for sensor and antenna components.

FOT sensor	Description	Mounting location	Remarks
Forward scene camera	KT&C Ex-Vision camera (B&W CCD camera with near-IR capability)	Inside-top of windshield	Field of view will be 30 – 40 deg horizontal & 10 – 15 deg vertical
Driver face camera	Marshall V1214-IR (B&W CCD, with IR illumination for interior night images)	Dashboard, near base of A-pillar	Field of view will include entire driver head and partial shoulders.
Driver microphone	Audio-Technica microphone	Center headliner area, near windshield	
Comment button	Illuminated push-button switch	To left of HVAC controls	
Steering wheel angle sensor	String potentiometer connected to steering wheel shaft	Below dash	
Accelerometer	3-axis	Under center console (under driver armrest)	Near CG
RF sensor	Zetron M150 is current candidate	In headliner, above driver	RF sensors do not cover all cell phone bands
Differential GPS	TBD	Roof unit, or possibly combined with cell modem antenna	1 or 2 Hz, satellite correction
Cell modem antenna	Cingular CDPD/analog service	Antenna on back windshield	Issue: Will analog service plans be available?

Table 6.1   DAS sensor and antenna components

6.5 Software provisions

The three processors on the DAS main module will use new and extended versions of software that UMTRI developed and used on other FOT projects. A more detailed description of software functions will be provided in the Field Operational Test Plan document.

6.6 Performance issues

The current list of data to be collected onboard the FOT vehicles is contained in the tables that follow. The upcoming Field Operational Test Plan will likely include

adjustments to these preliminary data tables, and will bring these lists to a more stable and mature point.

Data rates may be adjusted in the future for some variables, depending on the observed bandwidth of the various data buses, and the ability of the SAM to process and pass along some of the data to the DAS. The RDCW team will also work to identify and log data that will document data latencies, e.g., time stamps. This is significant because some data, such as the CSW's GPS readings, makes its way to the DAS via two or three steps, and analysts will need to minimize uncertainty in how the data lines up temporally with other data.

Original signal source	Forwarding subsystem
Vehicle bus (OEM CAN)	Situational awareness module (SAM), or directly read by DAS
Lateral drift warning (LDW) module	SAM
Curve speed warning (CSW) module	SAM
Forward radar system	TBD (direct or from SAM)
Side radar system	TBD (direct or from SAM)
SAM	SAM
Driver-vehicle interface (DVI) module	DVI
Data acquisition system (DAS)	n/a

Table 6.2 - DAS access to RDCW subsystems

Original signal source	Signal	When logged	Comments
Vehicle bus	Vehicle speed	transition	
Vehicle bus	Accel pedal position	triggered series	warning events
Vehicle bus	Brake pedal switch	transition	
Vehicle bus	Turn signals	transition	Left, right
Vehicle bus	Wiper signals	transition	categorical variable, e.g., off, low, med, high
Vehicle bus	PRNDL	transition	Park, reverse, neutral, D, 1,2, 3, 4
Vehicle bus	ABS/TC state	transition	if signal exists
Vehicle bus	Temperature	10Hz or trans	
Vehicle bus	Battery voltage	transition	categorical variable
Vehicle bus	Ambient light intensity	10 Hz	categorical variable
Vehicle bus	Headlight status	transition	
Vehicle bus	Fuel tank temperature	Transition	Evaluating signal as surrogate for outside temp
Vehicle bus	Cruise status	Transition	On/off, engaged/disengaged

Table 6.3 -Vehicle bus signals (from OEM CAN)

Original signal source	Signal	When logged	Comments
DAS	Driver number	once per trip	allows association with description of driver eg gender
DAS	Day	once per trip	
DAS	Trip number	once per trip	1= first trip of that day
DAS	Trip starting time	once per trip	
DAS	Trip duration	once per trip	
DAS	Trip distance traveled	once per trip	
DAS	RDCW alerts enabled?	once per trip	week 1 vs. week 2, etc
DAS	Accel X (long)	10 Hz	UMTRI sensor
DAS	Accel Y (lat)	10 Hz	UMTRI sensor
DAS	Accel Z (vert)	10 Hz	UMTRI sensor
DAS	Steering wheel angle	10 Hz	UMTRI sensor
DAS	"Comment button" press	transition	allows driver to dictate comments
DAS	Cell phone use (remotely sensed)	transition	UMTRI sensor
DAS	Video images of driver face	1 image/N sec + during episodes	Episodes include warnings, etc
DAS	Video images of forward scene	1 image/M sec +during episodes	Fwd scene episodes not nec. same as drvr face episodes
DAS	Audio of driver	episodic	triggered by comment button, alerts, and possibly other triggers
DAS	DGPS and associated signals	1 or 2 Hz	Lat, long, # sats, GPS speed, heading, DGPS lock

Table 6.4 -Data acquisition system signals (partial)

Original signal source	Signal	When logged	Comments
LDW	LDW data time stamp	10 Hz	
LDW	Vehicle lateral offset within lane	10 Hz	
LDW	Confidence in lateral offset	10 Hz	
LDW	Vehicle lateral velocity wrt lane	10 Hz	
LDW	Left boundary types	10 Hz	solid, dash, virtual, unknown
LDW	Right boundary types	10 Hz	
LDW	Lane width	10 Hz	
LDW	FOD left	10 Hz	future offset distance (m)
LDW	FOD right	10 Hz	
LDW	FODT left	10 Hz	FOD threshold (m)
LDW	FODT right	10 Hz	
LDW	Threat level left	10 Hz	alert request is imbedded here
LDW	Threat level right	10 Hz	
LDW	Confidence in left threat level	10 Hz	
LDW	Confidence in right threat level	10 Hz	
LDW	Ambient light level	Transition	Day, night
LDW	LDW self-calibration status	Transition	Categorical
LDW	Clean window request	Transition	
LDW	LDW system event codes	10 Hz	codes addressing LDW state, e.g., startup mode
LDW	Shoulder width estimate (left)	Transition or 10 hz	When available from LDW
LDW	Shoulder width estimate (right)	Transition or 10 hz	When available from LDW
LDW	Confidence in left shoulder width estimate	Transition or 10 hz	When available from LDW
LDW	Confidence in right shoulder width estimate	Transition or 10 hz	When available from LDW
LDW	LDW alert status codes	Transition	3 to 6 codes indicate reasons LDW is suppressing alert requests
LDW	LDW event codes	Transition	Codes describing self-calibrating event activities, lane changes, LDW status

Table 6.5 -Lateral Drift Warning Subsystem

Original signal source	Signal	When logged	Comments
CSWS	Health of CSWS processes	10 Hz	
CSWS	Software & hardware versions	Once a trip	
CSWS	GPS latitude	1 Hz	From RDCW's GPS, not the DAS's.
CSWS	GPS longitude	1 Hz	"
CSWS	# satellites	1 Hz	"
CSWS	GPS heading	1 Hz	"
CSWS	GPS time	1 Hz	"
CSWS	Yaw rate	10 Hz	
CSWS	No. of possible POMs (position on map)	TBD – as high as 10 Hz	POM = road selection from map matching.
CSWS	Most likely path (MLP) road attribute codes from map	TBD – as high as 10 Hz	All mapped roads: MLP Road Functional Class MLP Lane Category MLP Speed Catagory Only for Roads w/ ADAS: MLP Posted Speed MLP Advisory Speed MLP # Travel Lanes
CSWS	MLP Posted speed from map	TBD – as high as 10 Hz	For ADAS map coverage only
CSWS	MLP Advisory speed from map	TBD – as high as 10 Hz	For ADAS map coverage only
CSWS	MLP Dist to intersection	TBD – as high as 10 Hz	
CSWS	Confid in choice of MLP	TBD – as high as 10 Hz	
CSWS	MLP - lookahead dist	TBD – as high as 10	

			Hz	
CSWS	MLP – curvature points		TBD – as high as 10 Hz	(X,Y) in m for 20 points ahead, equally spaced in distance. Veh current locn is (0,0) in (North,East).
CSWS	MLP – curvature at each curvature point		TBD – as high as 10 Hz	1/m – details of encoding forthcoming
CSWS	MLP – lookahead distance		TBD – as high as 10 Hz	Travel dist to 20th point
CSWS	MLP – index of the curvature point of interest (CPOI)			Index from 1 to 20, with 0 denoting no CPOI
CSWS	Max safe speed, computed, for MLP CPOI		10 Hz	m/s
CSWS	Required decel to reach max safe speed, for MLP CPOI		10 Hz	
CSWS	Secondary option path (SOP, the alternative to MLP) - road attributes		TBD – as high as 10 Hz	Same as for MLP
CSWS	Learned driver reaction time		Transition	Stretch goal – to adapt to driver
CSWS	Threat level		10 Hz	Integer value between 1 and 100
CSWS	Confidence in alert level		10 Hz	
CSWS	Alert requested		Transition	No warn, alert, caution, imminent
CSWS	CSW yaw rate sensor fault		transition	
CSWS	CSW vehicle sensors fault		transition	

Table 6.6 -Curve Speed Warning Subsystem

Original signal source	Signal	When logged	Comments
Fwd radar	Time stamp	10 Hz	
Fwd radar	Number of tracks	10 Hz	
Fwd radar	Range (for selected tracks)	10 Hz	
Fwd radar	Range rate (for selected tracks)	10 Hz	
Fwd radar	Azimuth of centroid (for selected tracks)	10 Hz	
Fwd radar	Azimuthal alignment w.r.t. vehicle axis	once per trip	
Fwd radar	Radar status info	transition	
Fwd radar	Radome blocked	transition	
Fwd radar	Hardware/software versions	once per trip	

Table 6.7 -Forward Radar messages (for each of two radars)

Original signal source	Signal	When logged	Comments
Side radar	Time stamp	10 Hz	
Side radar	Detection status	10 Hz	
Side radar	Number of tracks	10 Hz	
Side radar	Range (for selected tracks)	10 Hz	"
Side radar	Range rate (for selected tracks)	10 Hz	"
Side radar	Azimuth (for selected tracks)	10 Hz	"
Side radar	Alignment w.r.t. veh lat axis	once per trip	
Side radar	Radar status info	transition	
Side radar	Radome blocked	transition	
Side radar	System status	transition	Availability, malfunction, etc
Side radar	Software/hardware versions	once per trip	

Table 6.8 -Side Radar messages (for each of two radars)

Original signal source	Signal	When logged	Comments
SAM	Time stamp or equivalent	10 Hz	
SAM	X & Yoffsets (veh location)	10 Hz	UTM coordinates
SAM	Heading w.r.t. north	10 Hz	
SAM	Position confidence	10 Hz	
SAM	Shoulder width estimates	10 Hz	For each left and right.
SAM	Shoulder width confidences	10 Hz	For each left and right.
SAM	Shoulder type estimates	10 Hz	For each left and right.
SAM	Maneuvering room, left	10 Hz	allowable clearance from lane edge
SAM	Manuevering room, right	10 Hz	
SAM	Confid in maneuvering room, left	10 Hz	
SAM	Confid in maneuvering room, right	10 Hz	
SAM	Curvature	10 Hz	
SAM	Health of SAM	transition	
SAM	Software/hardware version	once per trip	

Table 6.9 - Situational Awareness Module (SAM)

Original signal source	Signal	When logged	Comments
DVI	Fault detected	transition	Audio, haptic, display, SAM, etc
DVI	Driver's LDW sensitivity level	trans	
DVI	Driver's CSW sensitivity level	trans	
DVI	advisory/warning issued	Transition	categorical describing alert level and DVI presentation (e.g., audio, visual, haptic, alert level). Includes driver messages, e.g., malfunction, service needed, …
DVI	Status/Health of DVI	transition	e.g., available, healthy
DVI	Hardware/software versions	once per trip	

Table 6.10 - Driver-Vehicle Interface (DVI Module)

APPENDIX A RDCW SYSTEM ARCHITECTURE

Forward Radar — Front Left, Front Right

Side Radar — Left Side, Right Side

Radar CAN Bus 2 (500K)

Radar CAN Bus 1 (500K)

Nissan Vehicle ECU CAN Bus (500K)

Warning Enabled

Data Acquisition System (DAS) Module

Situational Awareness Module (SAM)

Driver Vehicle Interface (DVI) Module

Steering Wheel Angle

Cellular Antenna

Com-ment PB

Cell Phone Detect

Audio Mic

DAS Forward Camera

Driver Face Camera

Inertial Sensors

Gyro

CSW Sensi-tivity

LSW Sensi-tivity

RDCW System CAN Bus (500K)

Serial

Curve Speed Warning (CSW) Module

Lateral Drift Warning (LDW) Module

OEM Radio

Audio Matrix Module

Haptic Controller

Driver Display

OEM Amplifier

DVI

GPS Antenna

Navigation Module

ADAS Map

USB

CCD LDW Camera

Panel Link

Visteon

Road Departure Crash Warning FOT Project
Vehicle Architecture

Vehicle Architecture
M. Podhorsky, D. Bezzina, J. Wu
Rev 1.5 December 12, 2002
Printed Copies of This Document Are Not Controlled

RDCW FOT GLOSSARY

AASHTO	American Association of State Highway & Transportation Officials
ADAS	Advanced Driver Awareness Systems
AMR	Available Maneuverability Room
APSO	ADAS Product Set One
C	Maximum FODT
CAN	Controller Area Network
CSW	Curve Speed Warning
CSWS	Curve Speed Warning Subsystem
Curvature Point	Computed points within a segment to characterize road geometry
DGPS	Differential Global Positioning System
DNDC	Database for Navigation and Digital Cartography
DVI	Driver Vehicle Interface
FC	Functional Class (road classification within NAVTECH databases)
FOD	Future Offset Distance
FODT	Future Offset Distance Threshold
GDF	Geographic Data File (proprietary NAVTECH storage format for raw road data)
GPS	Global Positioning System
I/O	Input/Output
K1	Scale Factor to limit variability
K2	Offset to prevent FODT from dropping too low
LAD	Look Ahead Distance (distance ahead of vehicle of immediate interest to CSW algorithm)
LDW	Lateral Drift Warning
LDWS	Lateral Drift Warning Subsystem
m	meter(s)
Matlab	Engineering modeling application, for executing Simulink models

Min	minimum
mph	miles per hour
Node	NAVTECH map element for end points of each segment
PSF	Physical Storage Format (format styles available for Navigation applications)
R	Radius
RDCW	Road Departure Crash Warning
SAM	Situational Awareness Module
SDAL	Shared Data Access Libraries
Segment	NAVTECH map element for a portion of a road
Shape Point	NAVTECH map element for points within a segment to record curve shapes and over/under pass locations
Simulink	Engineering modeling language including model libraries, for use with Matlab
TL	Threat Level
Vistrax	Visteon testing and data logging applications, based on custom LabView models

Version 9/03