

Enabling Safety and Mobility through Connectivity

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ABSTRACT

Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) networks within the Intelligent Transportation System (ITS) lead to safety and mobility improvements in vehicle road traffic. This paper presents case studies that support the realization of the ITS architecture as an evolutionary process, beginning with driver information systems for enhancing feedback to the users, semi-autonomous control systems for improved vehicle system management, and fully autonomous control for improving vehicle cooperation and management. The paper will also demonstrate how the automotive, telecom, and data and service providers are working together to develop new ITS technologies.

INTRODUCTION

A primary goal of ITS is to provide substantial benefits in real world fuel economy, road congestion, and general road safety. ITS has its roots in leveraging leading edge technologies, beginning with driver-focused applications, building towards semi-automatic operations, and ultimately arriving at autonomous operations.

FROM SIMPLE FEEDBACK TO AUTONOMOUS SYSTEMS

A number of passive information systems are available to drivers today. Nowadays it is common for basic driver information systems to provide some kind of vehicle status relative to the environment. For instance, a basic collision warning system can alert the driver if there is an impending rear-end collision or if it detects a pedestrian obstacle. Similarly, a travel information system can alert the driver for upcoming road obstructions. By combining information from the immediate environment with longer-range environment, higher degrees of fuel economy and safety are achieved.

As an example of fuel-economy and safety improvements, Ricardo UK Limited with its academic, business, and ITS committee partners, have developed in-vehicle applications to provide feedback to the driver about fuel-economy and safety conditions. Currently available technologies, such as GPS, cell phone, back-office systems, are used. Two recent programs of note are

- **Foot-LITE** - A smart electronic co-pilot provides fuel economy information and impending economy-changing situations to the user. A small portable display unit is connected to ITS infrastructure and provides the vehicle driver real-time feedback about actual driving behaviour vs. ideal fuel-efficient behaviour. A web-based service provides historical trends for the driver and allows information sharing with other users.
- **Co-Driver** - An electronic hazard warning system provides situational awareness of road safety conditions and impending hazards. An in-vehicle unit processes hazard information such as steep grade, sharp curves, obstructions, etc., and provides advanced warning of the potential hazard. Co-Driver also indicates the degree of urgency the hazard presents to the user, for instance, a fallen tree across road versus routine road construction markers. Vehicle passengers can easily enter information back to the system in order to alert other drivers of transient hazards, such as obstacles in the road or accidents.

Applications such as these help the driver make decisions about driving habits and navigation. Reduced fuel costs, reduced CO₂ emissions, and safer driving are direct benefits of these technologies. In addition, even further advances are possible by utilizing semi-autonomous and autonomous technology.

CASE STUDY #1: SEMI-AUTONOMOUS “SENTIENCE”

Fuel efficiency can be improved by integrating topographical and geophysical data with automatic vehicle control subsystems. *Sentience* is a recently completed 2 ½ year collaborative R&D program that was co-funded by innovITS¹. It was jointly developed with six European partners: Ricardo, innovITS, Jaguar/Land Rover/Ford, Ordnance Survey, Orange, and TRL. The overall achievement of this program is the identification and development of a system to improve the fuel efficiency of vehicles using “electronic horizon” data collected with V2I communications. *Sentience* performs intelligent speed adaptation based on situational awareness.

Sentience is built using a web-based server and mobile client application. The server environment includes the telecommunications infrastructure, GPS satellites, weather data, ITS traffic data, historical traffic trend data, and the *Sentience* application web-server. The server translates data from the environment, categorizes them, and communicates them to the client using V2I.

The *Sentience* client application resides in a smart-phone mobile device that is part of the *Sentience* on-board system. The *Sentience* on-board system includes the GPS receiver, the mobile device (cell phone), and real-time supervisory controller unit (SCU). The vehicle interface software and supervisory control algorithms execute on the SCU. The SCU software communicates directly with the acceleration/braking subsystem electronics and over dedicated Ethernet with the client software on the mobile. The SCU software is responsible for optimization of regenerative-braking, air-condition boosting, and EV mode operations.

The team selected a Ford Hybrid Escape as the target vehicle for the prototype system. A hybrid vehicle presents several opportunities not available on conventional vehicles. The Ford Escape is a full hybrid vehicle and can operate in several modes: full electric, conventional combustion, and mixed (parallel) mode. It also utilizes regenerative braking.

SENTIENCE REQUIREMENTS AND SIMULATION

Phase one of the project focused on simulation and requirements specification. Ordnance Survey, Orange, and TRL focused on defining the vehicle routes and supporting data. Ricardo focused on simulation, control strategies, and prototype architecture. The team created and validated a vehicle model to assess baseline vehicle performance.

The primary opportunities found for energy savings are regenerative braking, EV usage during acceleration, and air-conditioning usage. Through measurement and analysis, the team found when it was best to run the electrical motor and when it was best to charge the battery based on road conditions and vehicle characteristics. This analysis allowed selection of optimum tradeoff points between electrical drive and conventional drive for vehicle speed and wheel torque.

U.S. EPA cycles were used to validate the model. Subsequent simulations included different route profiles and varying drive conditions, such as level or hilly routes, constant or varying speeds, with/without air-conditioning, head/tail wind, etc.

- Flat 12.4 mi route, 60mph
- 12.4 mi route (0.6mi flat, 3.7 mi uphill, 7.5 mi downhill, 0.6 mi flat), 60mph
- Flat 12.4 mi route, 30mph, air-conditioning turned on
- Flat 12.4 mi route, variable speed (multiple discrete target speeds) with average of 30mph
- 12.4 mi route (0.6 mi flat, 11.2 mi of repeated alternate 0.6 mi uphill, 0.6 mi downhill gradients, 0.6 mi flat to end), 30mph

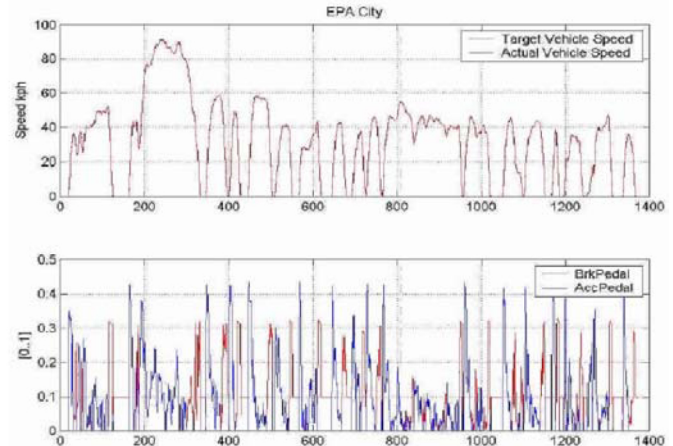


Figure 1. EPA Test Cycle

The on-board *Sentience* architecture incorporates V2I communications to access electronic horizon data, such as topographical, geographical, and traffic data, from the *Sentience* web server. The team performed a sensitivity analysis of the look-ahead algorithm to characterize how deep the queue of traffic/map data must be in order to maximize efficiency of the algorithms and to account for temporary interruptions of service. As a result, the on-board *Sentience*

^{1,2} innovITS is the UK Centre of Excellence for sustainable mobility and intelligent transport systems. See <http://www.innovITS.co.uk> Simulink® is a registered trademark of The MathWorks™.

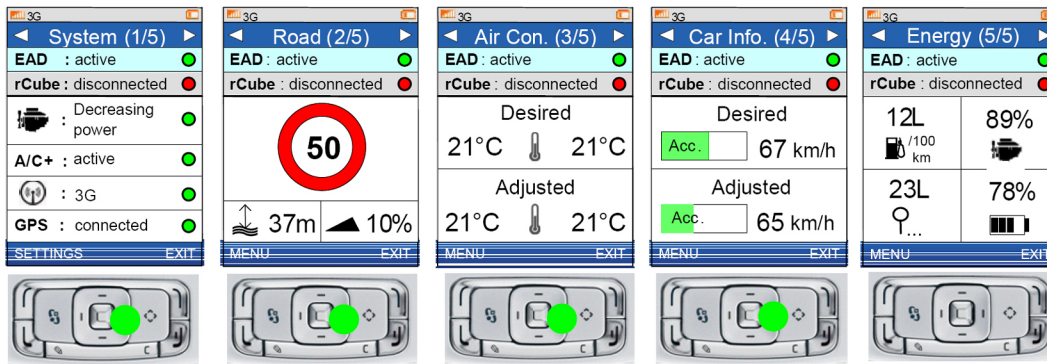


Figure 2. Sentience HMI sample

system views an electronic horizon of up to 3 miles to calculate optimum acceleration/regeneration potential.

A key requirement of the on-board system was a safe implementation with minimal cost. For this reason, a Ricardo rapid prototyping system was selected for the SCU. The SCU intercepts and overrides controls for cruise control and air conditioning. It communicates with the powertrain controller for hybrid, engine, and safety functions. A safety cut-off function for the enhanced acceleration and deceleration was identified as being required during the preliminary safety analysis.

The team, with input from Ford, assessed vehicle systems for suitability, and concluded that a small amount of additional hardware was required to ensure the vehicle system did not raise faults against the cruise control or air conditioning switchgear.

SENTIENCE DEVELOPMENT AND ASSESSMENT

Phase two of the project focused on development, integration, and assessment.

A Nokia N95 cellular phone served as the mobile communications device and human-machine interface (HMI) for the on-board system. For convenience, an external GPS was connected to the phone to provide location information. Ricardo and Orange defined and implemented a telecommunications protocol for communication between the phone and the SCU. Ordnance Survey data provided the historical traffic data. For future use, the *Sentience* architecture supports the use of real-time traffic data from ITS infrastructure sources. *Sentience* focuses on three main areas of system operation to optimize energy storage and transfers: engine loading, air-conditioning, and acceleration/braking. See discussions on OEL, EAC, and EAD below.

The *Sentience* HMI on the mobile device displays road information as well as *Sentience* status information, e.g.,

- Road speed limit, height and gradient

- Enhanced Air-Conditioning level desired and adjusted temperature set-point
- Enhanced Acceleration/ Deceleration level desired and adjusted vehicle speed
- Energy status information such as battery state of charge

Sentience detects when the vehicle is approaching significant changes in driving conditions due to traffic or geography, and displays pop-ups on the HMI. A configuration screen allows the user to select the desired features. The user can selectively enable and disable both pop-ups and audio messages by feature.

Sentience subsystem components are discretely installed in the vehicle under the passenger seat and in the dash. *Sentience* components include a custom harness, a modified A/C control unit, a custom cruise-control unit, the SCU, a wireless router & GPS receiver, and a CAN data logger device.

Sentience Optimized Engine Loading (OEL) executes on the SCU and optimizes the efficiency of the hybrid powertrain through intelligent management of electric, mixed and combustion modes of operation. The OEL algorithm communicates to the powertrain controller via the CAN network and provides supervisory control. Advanced knowledge of opportunities to recharge the battery system allows more flexibility in EV use, e.g., the battery state of charge limits are adjusted with the vehicle operation utilizing these limits. Ricardo developed supervisory control strategies in Simulink® for execution on the *Sentience* SCU. With the current OEL strategies, a 4-9% improvement in fuel consumption is realized.

Sentience Enhanced Air Conditioning (EAC) executes on the SCU and optimizes the A/C operation in order to reduce the CO₂ emissions from the vehicle. Because the combustion engine drives the A/C compressor directly, a specialized strategy was developed to keep the passengers comfortable during extended vehicle stops. EAC overrides the A/C switchgear signals and “pre-cools” the interior 1 or 2 degrees