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Intelligent Infrastructure for Testing and Evaluation of Electric Vehicle Performance

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Abstract

This paper will present the remote data monitoring system being deployed to analyse electric vehicle energy efficiency, range and carbon emissions. An automated system to monitor the electric vehicle performance is being designed, implemented and evaluated. Data from the vehicle’s CAN bus, on board diagnostic ports, discreet sensors, battery monitoring systems and geographic positioning systems are integrated to build a full knowledge picture. The vehicle’s performance is assessed in terms of its energy regeneration and its drive efficiency with respect to altitude; the congestion state of the road and thereby the battery consumption is categorized for each individual journey. The system evaluation will illustrate the carbon emissions of a similar fossil fuelled vehicle through onboard simulation for concurrent journeys.
Bibliographical details

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UNIVERSITY OF NEWCASTLE UPON TYNE

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About the author
Lakshmi joined the computing science department as Research Associate in the MESSAGE project in November 2006. She is currently working in TSB funded EVADINE project to build infrastructure for Electric Vehicles Monitoring. She is a member of core technology group to support database infrastructure in SIDE (Social Inclusion of Digital Economy). Her current area of research interests are in buliding scalable real time event processing system on cloud. She received her Bachelor of Engineering degree in 1996 from the Bharatidasan University, India and the Master of Science (SDIA) with distinction in 2006 from the Newcastle University, United Kingdom. After completing her bachelor’s degree she worked for LogicaCMG and Indigo4 Systems United Kingdom in client server technologies. During her post graduation studies, Lakshmi worked for PrismTech in the Open Splice DDS, a middleware addressing publish-subscribe communications for real-time and embedded systems.

Phil Blythe is Professor of Intelligent Transport Systems and Director of the Transport Operations Research Group. His research interests cover a range of ITS areas and focus on the fusion of technology and policy themes. These include road user charging, smartcard systems, wireless ad-hoc networks, telematics to support elderly and the mobility impaired and mobile information delivery systems. He is internationally recognised as an early pioneer of ITS research and holds several international, European and National positions in the ITS arena. Phil’s main area of research is in fields related to ‘Intelligent Transport Systems’. This covers the innovative use of new technologies, fundamental technical and applications research, demonstrations, proof-of concept, evaluation, delivering the evidence base and informing policy. Although the research covers a wide portfolio, key areas of research include road user charging, e-tolling, demand management, the use of smartcards for transport, ID and citizen-card applications, delivery of information to mobile sources, mobile ad-hoc wireless systems and sensors, intelligent infrastructure and policy/technologies issues related to transport/energy/environment low-carbon transport and climate change.

Dr Graeme Hill has a background in experimental physics but more particularly nanotechnology with a specialism in Scanning Probe Microscopy and the analysis of the data generated by this technique. He gained his BA and MSci in Experimental Theoretical Physics at Cambridge University and his PhD (Fabrication and Characterisation of Nanowires) from Newcastle University. His main expertise/research interests include the analysis of data from a distributed network of sensors and calibrating data from multiple low cost sensors against high cost sensors. He is currently working within the MESSAGE and 4M project and is involved with a patent for a novel spectroscopic technique.

Eric Sampson is a Fellow of the Transport Research Foundation and a Visiting Professor at Newcastle University and City University London. He was elected Chairman of ITS-UK in May 2007 and was appointed CBE in the Queen’s Birthday Honours List 2007. Eric worked in the UK public sector for for 39 years, retiring in November 2006. At the Department for Transport he worked in the Marine, Highways, Rail and Safety Directorates, as well as The Coastguard Agency. In 1997 Eric was appointed the first Director of Road User Charging Research and in 2000 set up DfT’s Transport Technology and Standards Division working on information systems, road user charging, smart cards, vehicle safety and innovative transport technologies. He was a founder member of the international study group that led to the formation of ERTICO and has been a member and Chairman of its
Supervisory Board. In 2009 he was elected the first President of IBEC – the international collaboration for ITS Evaluation, Benefits and Costs.

**Suggested keywords**

- ELECTRIC VEHICLES
- CARBON FOOTPRINT ANALYSIS
- INFRASTRUCTURE FOR EV MONITORING
Intelligent Infrastructure for Testing and Evaluation of Electric Vehicle Performance

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ABSTRACT

This paper will present the remote data monitoring system being deployed to analyse electric vehicle energy efficiency, range and carbon emissions. An automated system to monitor the electric vehicle performance is being designed, implemented and evaluated. Data from the vehicle’s CAN bus, on board diagnostic ports, discreet sensors, battery monitoring systems and geographic positioning systems are integrated to build a full knowledge picture. The vehicle’s performance is assessed in terms of its energy regeneration and its drive efficiency with respect to altitude; the congestion state of the road and thereby the battery consumption is categorized for each individual journey. The system evaluation will illustrate the carbon emissions of a similar fossil fuelled vehicle through onboard simulation for concurrent journeys.

INTRODUCTION:

The European Union New Car CO$_2$ Regulation [8] defines a framework for industry to develop low carbon emission vehicles. In the UK this Regulation is expected to reduce emissions by 7 million tons of CO$_2$ a year till 2020. Electric vehicles claim to be a “zero emission”, irrespective of the carbon footprint involved in the electricity generation. To have an absolute impact, the EVs must be accompanied by “decarbonisation” of their electricity supply. Any electric vehicle initiative will also need to be complemented by a wide range of infrastructure which must include vehicle recharging points. As the technology improves, convenient recharging points will become increasingly important.

Migrating to cleaner forms of transport cannot be handled by a single technology. To address this a UK Government body, the Technology Strategy Board (TSB), has supported SWITCH-EV, a national demonstration project to monitor the practical range of electric vehicles and thereby help to assess the technical and social aspects of living with an all-electric vehicle.

Research groups at Newcastle University are monitoring the EV studies in the North East of the UK where nearly 30 electric vehicles will be tracked using data loggers correlated with charging infrastructure. The state of battery charge in a vehicle is vital information to be monitored constantly and updated consistently for the vehicle user. The level of battery
discharge will depend on various factors such as auxiliary and total-loads, topography of the drive, weather, and usage of heating or additional electric equipment in the car.

In advance of the start of the SWITCH-EV programme, the Newcastle University team extensively tested their EV monitoring infrastructure on a fleet of vehicles provided by CENEX (the UK Centre of Excellence for Low Carbon and Fuel Cell Technologies). The vehicle performance and evaluation was done in a Smart car (Mercedes), model-Fortwo ed (electric drive), 20kW motor power, 15kwh energy storage capacity, sodium nickel chloride battery, 13 amps at 240v charging with a maximum range of 60 mph. The vehicle deployment was tied with local city council employees who acted as electric vehicle hubs that could manage vehicles to participating organizations in their area.

**SYSTEM ARCHITECTURE:**

A multi-tier architecture is used in the information management for tracking, monitoring, analysing and knowledge discovery of the in-car pervasive sensing network.

The first tier involves low level sensor layer communication adapters connected to the in-car communication systems such as CAN and OBD. The content oriented architecture of the CAN messaging provides a high level of flexibility for the abstraction of in-car sensing network monitoring. Parameters that change quickly such as current, braking *etc* are transmitted more frequently and given higher priority and use maximum capacity of the communication bus. The messages from the CAN bus are captured by the sensor device in figure 1. The device as illustrated receives data streams from the CAN, OBD and GPS. The primary data acquisition system currently functions as a data logger with wireless data transfer to the central server at the end of each journey when the ignition is switched off. The performance analysis of the vehicles starts with the vehicle management units which have customized features specified by individual vehicle manufacturers as described below:

- Three channels are measured – battery current, battery voltage and level of discharge.
- Distance, velocity and altitude calculated from GPS monitoring systems.
- Auxiliary power unit (APU) on/off activity
- Braking activity
- Activity is recorded from windows, internal heating and lights.
- 2 GB of on-board memory
- Sampling frequency once every second during driving and sampling of every minute is recorded off drive.
- Data transfer through GPRS to the central server once the ignition state is changed from on to off.

The second tier is the sensing event processing middleware tier which acts as a layer to support interoperability between web servers, application servers, rule engines and similar tools to support the application hosting and delivery. The middleware layer acts as an integral to the information management layer based on service-oriented architecture. The performance monitoring of the vehicle needs to aggregate the data from heterogeneous
sensing layers and assess the performance of each trip. The integration of the sensing information is carried out with a predetermined rule base as described in Suresh et al [1]. The system performance failures assessment in terms of removal of duplicate sensing observations, temporal synchronisation of the sensing data, anomaly detection arising out of spurious current and voltage events, location transformation in terms of GPS map-matching are all carried out in this middleware interface engine.

The third tier, the data base and data warehouse layer, acts as a persistence layer for the raw, processed and mined information. The relational architecture is followed in storing the data. The statistics describing the performance of the vehicle are obtained by the processing of the raw data which is a continuously evolving process. To enable a long term research project the intelligence behind the processing of the vehicle data is stored in the systematic approach thereby enabling data provenance to be tracked. The warehouse acts as a main repository to maintain the data provenance and the historic datasets. The warehouse is classified with data marts each categorized to a specific work package of the data analysis.

The information propagation layer is the fourth tier which handles the messaging systems. Information about every individual journey by the vehicle is summarised from the base data collection and made available for further dissemination using various modes such as web site, mobile phone and e-mail alerts.

**EVALUATION RESULTS:**

In order to study the effects of different factors on energy regeneration, energy efficiency, range and carbon emissions of electric vehicles the following detailed analyses are being undertaken:

**Energy Regeneration:**

The energy regeneration occurs in vehicles due to topography of the road conditions and the driving behaviour such as regenerative braking. The topography of the road such as driving in a downhill segment will produce the largest regenerative events. The trained user with electric vehicle driving knowledge would generate more regeneration events irrespective of the topography thus exhibiting a high level of eco-friendly driving. The analysis results are produced from the driving results from the untrained pool of users. In figure 2 regeneration events indicated in the topographic map are coloured in green. The graph is plotted with energy consumption and altitude. Through a visual examination of the graph, the largest regeneration events colour coded in green occur in the downhill journey.

The electric vehicles have regenerative power capabilities. The regenerative braking in the vehicles uses a mechanism which reduces vehicle speed by converting its kinetic energy into a useful form of energy rather than dissipation as heat. During regenerative braking the electric drive motors are used as generators with the output supplied to an electrical load; the transfer of kinetic energy to the load provides the braking effect. The energy is stored in the vehicle’s main battery and used to power the motor thereby increasing the range. Figure 3 shows the power consumption and state of charge in the
battery for an example 25 minute trial journey. When the vehicle is on the move the power consumption is positive; the power value is negative during the regeneration state. The closer observation during the high power operations, the battery state of charge reduces significantly. Frequent stop–starts representative of congested traffic flow allow numerous regenerative events. Larger regeneration is available during coasting or braking after high speed running.

**Carbon footprint:**

The CENEX trials have been calculated based on the UK electricity grid generation mix. The Department for Environment, Food and Rural Affairs (DEFRA) [4] issues emission factors relating to the electricity generation types. The emission factor used in this evaluation is 544.2 g CO2/kWh electricity for the UK national grid mix. The CHP emissions are calculated based on 301.1 g CO2/kWh. Figure 4 shows the carbon emissions for each trip plotted against the average and rolling average speed of the trip.

**Journey Efficiency:**

The journey efficiency is calculated based on the distance travelled with respect to the energy usage in terms of state of charge. The trials were conducted in one of the worst winters ever faced in the UK with significant temperature drop. Figure 5 illustrates how journey efficiency decreases with lower temperature. Both high and low temperature tend to lead to an increase in power usage because of the deployment of heating or air-conditioning respectively; hence the ambient temperature affects the range and performance of the vehicle. Also, the energy used to keep the battery at the ambient temperature increases during the winter.

Figure 6 illustrate the correlation between the journey efficiency and the battery regeneration. Note how battery regeneration events significantly increase with the increase in the journey efficiency.

**Energy regeneration and driving behaviour:**

Quantification of the variation of range and vehicle performance from a wide variety of users has prompted a new area of algorithm development to classify driving styles (e.g. aggressive or gentle), for both acceleration and deceleration behaviour and the consequent effect on energy consumed and regenerated. Figure 7 shows identical spatial journeys which illustrate different regimes of battery drain based on the driving behaviour. Whilst a detailed model of a single driver will not be viable using the (relatively) small number of trips, it may be possible to broadly classify a driver into categories such as “efficient”, “range wary”, “aggressive” or “cautious”[9].

**Visualisation of data:**

Visualization can show differences which are difficult to spot with numerical statistics. Simple things such as total energy consumption with respect to the change in the altitude or braking can be easily identified in a geographic representation of the data. The exemplar from one such trip is illustrated in Figure 8 which was carried out around The Metrocentre, Gateshead, in the UK during a public drive event to publicise electric vehicles.
The colour coding is based on the energy consumption ranging from green (lowest) to red for the highest energy consumption.

The summary of each trip is illustrated in Table 1 demonstrating the complete analysis showing energy consumption, regeneration, average speed, temperature, carbon footprint and trip time.

**FUTURE WORK:**

Most observers predict a rapid and sustained increase in the numbers of electric vehicles, whether plug-in hybrid or all-electric, and recognize that at some point these changes in the composition of a country’s vehicle fleet will require matching changes in infrastructure provision and management. The need for enhanced generation capacity coupled to ‘smart’ distribution networks and ‘smart’ domestic metering is already recognized and many studies are underway examining these issues. Less obvious is the possibility that traffic management processes will need to change as well if the EV fleet is used in a different way from current internal combustion-engine vehicles.

The key unknown is recharging attitudes – the equivalent of refueling for the current fleet – which is one of the subjects of the research. The petroleum retail industry has over 100 years’ experience of demand patterns and the behavior of individual drivers: the degree to which they rely on in-vehicle gauges and odometers to guide their decision to take on fuel and their acquired knowledge of the likelihood of finding fuel within a given time or distance. None of this experience translates to an electric world and the few studies that have been carried out so far suggest that drivers are liable to “range anxiety” and look for an opportunity to recharge well before they really need to do so.

The ITS community has for some years now researched the idea of Cooperative Vehicle–Highway Systems (CVHS): close collaboration based on real-time information exchange between road operators, infrastructure providers, telecoms companies, vehicles, their drivers and other road users to deliver the most efficient, safe, secure and comfortable journeys to travelers and more productive network capacity combined with reduced tailpipe emissions. We believe that successful deployment of EVs needs to go hand-in-hand with the deployment of CVHS applications so that

- Drivers can be presented with continuously updated information linking their route, speed and the location of different types of recharge facility to reduce stress and optimise route choices and driving styles
- Infrastructure operators can be confident that electric vehicles entering a network have sufficient ‘fuel’ to be within range of a choice of recharge stations and can be part of area traffic management strategies in the same way as ICE vehicles.

In other words successful adoption of EVs will require matching deployment of ITS.

**CONCLUSION:**

The automated performance evaluation system currently summarises each trip undertaken by
a car and disseminates useful information to the user in terms of power consumption, power regeneration, battery state of charge, range, carbon footprint, speed and distance travelled. The journey efficiency is clearly shown to the driver which demonstrates the driving behavior of the car user. The feedback generated from the system will affect the extent to which the user elects to change driving and vehicle performance. The results are presented in this paper based on the trials undertaken by Newcastle University in collaboration with CENEX[3]. The significant reduction of the carbon footprint by using low carbon energy sources is shown in the trip summary results.

It needs to be borne in mind that whereas we have 100+ years’ experience of traditional vehicles’ behaviour we have less than 100 months for hybrids and less than 100 weeks for all-electric vehicles. The challenges for Intelligent Transport Systems are exciting and we will continue to report our findings at future World Congresses.

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TABLES, FIGURES, AND ILLUSTRATIONS

Figure 1: System Architecture

Figure 2: Battery Regeneration with altitude

Figure 3: Power consumption vs Battery State of Charge (SoC)/Discharge

Figure 4: Effect of carbon footprint (g/Km) on the Speed (Km/hr) averaged for each trip.
Figure 5: Effect of Ambient temperature on the journey efficiency

Figure 6: Correlation between journey efficiency and battery regeneration rate.

Figure 7: Latitude, Longitude vs Battery drain
Figure 8: Trip summary demonstrating energy consumption or regeneration related to topography.

<table>
<thead>
<tr>
<th>Vehicle Identifier</th>
<th>14</th>
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<tbody>
<tr>
<td>Trip Identifier</td>
<td>444</td>
</tr>
<tr>
<td>Start time of the trip</td>
<td>25/02/2010 02:04:31</td>
</tr>
<tr>
<td>End time of the trip</td>
<td>25/02/2010 02:10:26</td>
</tr>
<tr>
<td>Power Consumed</td>
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<tr>
<td>Power regenerated</td>
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</tr>
<tr>
<td>Power Used</td>
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<tr>
<td>Battery State of Charge during the start of journey</td>
<td>99.88%</td>
</tr>
<tr>
<td>Battery State of Charge during the end of journey</td>
<td>94.63%</td>
</tr>
<tr>
<td>Temperature</td>
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</tr>
<tr>
<td>Break pedals pressed</td>
<td>2.75 km</td>
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<tr>
<td>Distance</td>
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<tr>
<td>Speed</td>
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<tr>
<td>Carbon foot print</td>
<td>107.3 g CO\textsubscript{2}/km</td>
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<tr>
<td>Journey efficiency</td>
<td>.53</td>
</tr>
<tr>
<td>CHP(Combined heat and power) emissions</td>
<td>67.32 g CO\textsubscript{2}/km</td>
</tr>
</tbody>
</table>

Table 1: Summary for the trip shown in Figure 8.