Building a Driving Simulator as an Electric Vehicle Hardware Development Tool

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Abstract *– Driving simulators have been used to support the development of new vehicle systems for many years. The rise of electric vehicles (EVs) as a means of reducing carbon emissions has lead to the emergence of a number of new design challenges related to the performance of EV components and the flow of power under a variety of circumstances. In this paper we describe the integration of an EV drive train test system with a driving simulator to allow the performance of EV systems to be investigated while under the control of real drivers in simulated scenarios. Such a system offers several potential benefits. The performance of EV drive trains can be evaluated subjectively by real world users while the electrical and mechanical properties can be tested under a variety of conditions which would be difficult to replicate using standard drive cycles.*

Key words: *Driving Simulation, Hardware testing, Electric Vehicles, Simulator Control, Vehicle Design*

Introduction

As the world faces ever growing pressures to reduce carbon emissions, Electric Vehicles (EVs) are seen as a potential replacement for conventionally fuelled vehicles. First generation mass produced or converted electric vehicles are now on the market and are receiving widespread recognition. Many drawbacks remain, however, and it is crucial that improvements are made to make the next generation of vehicles to suit the requirements of users. The driveability of vehicle as experienced by the user is a particular area of concern.

Alongside the experience gathered from current EV models and trials, we believe that driving simulators have a major part to play in ensuring human factors are given appropriate consideration in the design process. The key technical requirements for future EV development include thermal management, range optimisation, control strategies and transmission design. Alongside these technical considerations Crolla et al [Cro1] have identified 3 areas for additional research to ensure EVs are viable and attractive in real world conditions:

1. Driveability – optimisation research should be based upon realistic driving conditions rather than standard patterns.
2. Braking behaviour – regenerative braking means energy can be recovered but such systems should not compromise safety.
3. Practical design – research currently done leaves many implementation issues; e.g. some methods for control are just too computationally intensive.

Research and development in these areas makes extensive use of the hardware-in-the-loop (HIL) methodology where hardware can be combined with simulated elements to achieve HIL tests (c.f. [Bou1], [Ros1]). Zha and Zong [Zha1] describe the use of an electric motor to act as a dynamometer for simulating the inertia of an electric vehicle. Jun Liu et al [Jun1] describe the use of an electrical load for simulating the motor in drive train experiments. Such activities utilise drive cycles which consist of a pattern of use in terms of vehicle speed through time. At present much of the power system simulation and modelling work is based on standard drive cycles. This has the advantage of providing a snapshot of performance and allowing easy comparison. The usefulness of standard drive cycles is, however, restricted by the accuracy of the assumptions upon which it is based. In order to achieve greater realism it is necessary to look for more realistic drive cycles [Saj1][Ado1] and a variety of techniques are beginning to receive attention to address these [Wal1][Hiw1].

In this paper we will describe an architecture for using a driving simulator as a control mechanism for HIL tests creating a new development platform capable of supporting Human-in-the-Loop (HuL) testing. A bespoke dynamometer developed at the University of Sunderland [Kno1] will be integrated with a Forum8 3D driving simulator to allow hardware to be tested under the direct control of a driver travelling around a real route.

The remainder of the paper is structured as follows. The motivation for the test system is summarised in the following section. This is followed by a description of the two major system components: the dynamometer and the driving simulator. The integration strategy for these two components is then discussed followed by a section considering the ongoing work to realise such a system.

Motivation

An integrated hardware test system controlled by a realistic immersive driving simulator has many potential benefits. Electric vehicle (EV) design issues listed above can be evaluated and improvements developed using realistic driving patterns. Furthermore feedback can be obtained on the performance of traction system configurations by drivers without the need to create expensive test vehicles. The effect of control strategies on driver behaviour can also be investigated in real time using easily varied control systems. Finally, the driving simulator software can be used to create different test routes which can be either designed specifically to investigate certain aspects of performance or which recreate real road systems, the latter will also allow for cross validation with data captured from test vehicles driven around standard laps. It is our contention that the development of such a system has much to offer EV research and development programmes.

Driving simulator

The University of Sunderland driving simulator laboratory was established in 1999 and has been used to support research in a variety of areas relating to vehicle design and human factors (c.f.[Mid1][Mid2][Mid3]). The laboratory presently houses two driving simulators. The system which has been utilised for these experiments is the most recent system which has been used for a variety of work including eco-driver training [Sco1] and assessment of driving style [Kno2].

The hardware component of the simulator is a Forum8 Driving Simulator and is illustrated in Figure 1. The hardware is based around a vehicle cockpit comprising all the usual controls including steering wheel, transmission selector, parking brake, accelerator and brake. Instruments include speedometer and engine speed measurement. The display consists of three 32 inch LCD screens, each with a resolution of 1024x768 pixels and a fourth, smaller 8.4 inch LCD TFT screen with a resolution of 800x600 pixels which can be used for display of navigational information or other data to the driver.

Fig.1. Forum8 driving Simulator

This simulator has been selected for the work for the following reasons:

- The ease with which simulated versions of real routes can be created using GPS or mapping data using the LandXML data format for import.
- The provision of a plug-in based architecture allowing bespoke software components to be developed giving access to the appropriate internal data structures.

Dynamometer

The Dynamometer which will be used for the test system was rebuilt in 2011 to provide bespoke test facilities for EV drive train components. The system consists of a Froude Hofmann EC38TA (Eddy Current) dynamometer, shown in figure 2, which is controlled from a Texcel V4 ECE/HE controller, shown in figure 3.

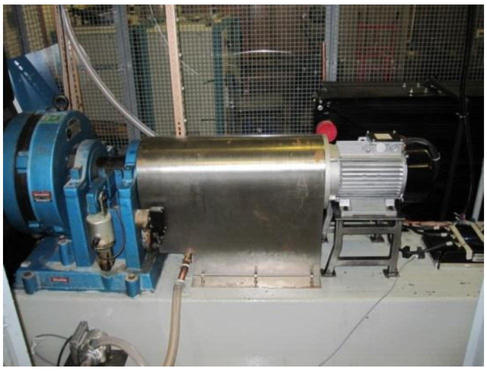

Fig. 2. Dynamometer hardware

Fig.3. Dynamometer control and datalogging equipment

The dynamometer is currently fitted with an EV drive train which consists of:

- A 15kW (30kW peak) induction motor controlled through a Curtis motor controller. The Curtis motor controller can be programmed and controlled via CAN bus.
- A Lithium-ion phosphate pack of 29 3.2V 90Ah cells (8.352 kWh 100% discharged) with individual battery management cell controllers and overall battery management monitoring module with CAN connector.

These drive train components can be fully or partially replaced with any system which requires testing. Other components currently available for testing include alternative lithium-ion power cells and a variety of hydrogen fuel cells.

In terms of instrumentation and control, the system features a Murphy Power View (PV)750 display which features 3 separate CAN ports, 3 analogue I/O ports and internal memory for data logging. In its current configuration two options exist for controlling the system:

1. Manually through a linear actuator, much like a throttle pedal in a vehicle. This option is primarily used for testing purposes.
2. Programmed operation via the Murphy display. The PV750 can be loaded with a drive cycle and when started it will control the motor controller and the dynamometer, while recording data.

The data capture system currently consists of 4 parts:

1. A 4 band digital oscilloscope which is connected to a computer for data logging. This system is used to record electrical transients in the motor power system with high speed recording.
2. Two CAN connections allow for data logging from the motor controller (voltages, current, motor and controller temperature) and BMS (cell number of highest voltage, cell number of lowest voltage and temperatures of respective cells).
3. A USB connection from the Battery Management System (BMS) to computer for capturing voltages, temperatures and state of charge (SoC) for cells within the battery pack.
4. Analogue data capture from the dynamometer controller via the Murphy PV750 of torque and speed.

Both the CAN connections (2) and analogue data capture (4) are done through the PV750 at a maximum speed of 50Hz.

The current system has been designed primarily to investigate the electrical behaviour of EV drive systems, however it should be emphasised that the instrumentation and data capture system can be easily customised using the reprogrammable nature of the Murphy display unit and the Curtis motor controller.

Integration design

Control of the test motor on the dynamometer will be achieved using data captured from the simulator controls. The mechanical load imposed by the dynamometer will be based around the mechanical characteristics of the vehicle as well as surface properties of the road and aerodynamic factors and the gradient upon which the simulated vehicle is travelling [Lar1]. The speed at which the motor turns under that load will be measured from the dynamometer and fed back via an inverse vehicle model to the simulator to control the speed of the simulated vehicle. The proposed system structure is illustrated in figure 4 below.

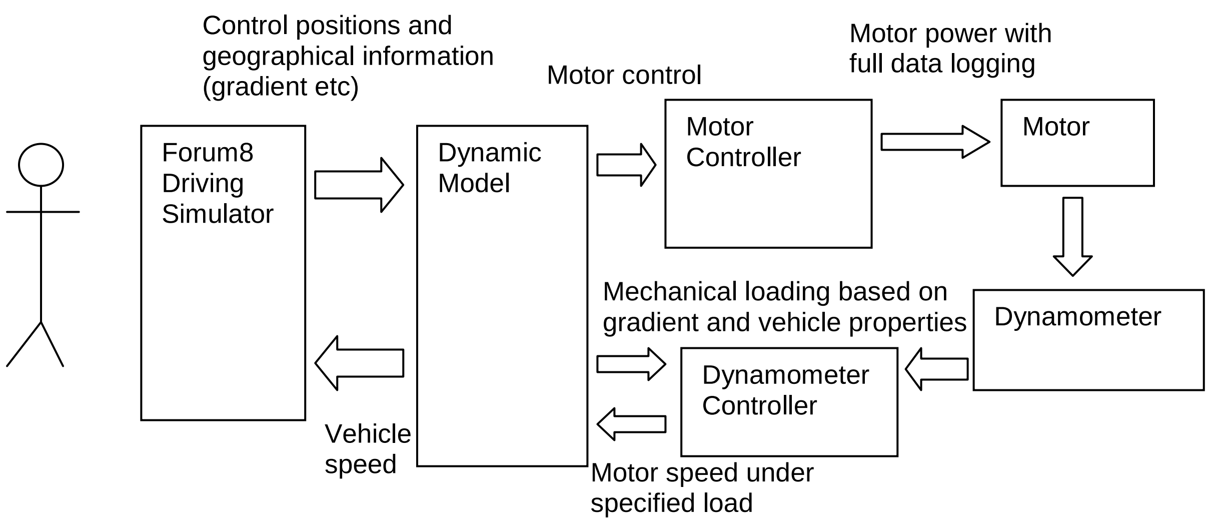

Fig. 4 System structure illustrating data flow

A number of key requirements for the system have been determined. These will be discussed in the following sections.

Data rate

One of the key considerations for the system viability is the speed and latency of the system such that the dynamometer system reacts to changes in throttle position and feeds back speed changes fast enough to ensure that the driver feels the experience is realistic. The effect of ‘transport delays’ has been widely investigated over a number of years (c.f. [Lee1]). The frame update rate offered by the simulator is 20 Hz (under current development conditions) so the objective for this integration is for the total round trip communication time to be within the time period of the frame update i.e. 50ms.

Safety

The primary safety concern for the dynamometer is a stall condition since this will be detrimental to the motor and controller potentially causing extensive, costly to repair damage. Also, sudden stall could lead to a break in the drive shaft. Such a condition should therefore be avoided at all times. In addition to standard safety features already installed on the dynamometer such as cut out switches and temperature monitoring, the following additional safety protocols have been identified as being necessary:

- Upon detection of both a brake and a throttle signal, the brake signal will be passed on to the controller while the throttle signal will be set to zero. This practise is used inside the Curtis motor controller as well.
- All values sent to the motor and dynamometer controller will be capped at their respective minimum or maximum values
- Upon switching off the simulator or if the connection with the simulator is lost the control signals to the motor will be set to zero.

Simulator control

As discussed previously, a plug-in software component is under development for the driving simulator. This will fulfil a dual role:

- Data will be extracted from the simulation regarding the throttle and brake controls, as well as the gradient on which the vehicle sits.
- Data from the dynamometer will be used to control the speed of the simulated vehicle.

The plug-in is under development in the Delphi programming language using the Forum8 UC-Win Road SDK version 5.02.04.

Dynamic model

The dynamic model of vehicle properties is based upon that proposed by Larminie and Lowry [Lar1]. This model is used in the first instance to determine the mechanical torque which must be applied to the motor to simulate the tractive effort required to propel the vehicle. This will depend on a number of factors including the gradient of the road – if the vehicle is travelling uphill more effort is required.

The tractive effort F_{te} is the sum of four distinct factors:

$$F_{te} = F_{rr} + F_{ad} + F_{hc} + F_{la} \qquad (1)$$

The four factors are:

1. Rolling road resistance. This is caused by the effect of frictional forces acting at the wheel/road interface and is dependent on the coefficient of rolling friction μ_{rr}:

$$F_{rr} = \mu_{rr} * m * g \qquad (2)$$

Where m is the mass of the vehicle and g is the acceleration due to gravity.

2. Aerodynamic drag. This is the frictional effect of the vehicle moving through the air:

$$F_{ad} = \frac{1}{2}\rho * A * C_d * v^2 \qquad (3)$$

Where ρ is the density of air, A is the vehicle frontal area and C_d is the drag coefficient, a value based on A.

3. Hill climbing force. This is the mechanical effort required to overcome a gradient, expressed as an angle, α. If the vehicle is travelling downhill then this will become negative:

$$F_{hc} = m * g * sin\,(\alpha) \qquad (4)$$

4. Lateral Force. This force represents the inertia of the vehicle and its rotating components and is estimated on the basis the inertia as a percentage of the vehicle mass, I and the vehicles acceleration a.

$$F_{la} = I * m * a \qquad (5)$$

Since the dynamometer is not connected to the motor by a final drive gearbox it is necessary to account for this. Therefore the torque to be applied at the dynamometer is give by τ:

$$\tau = F_{te} * \frac{r}{G} \qquad (6)$$

Where r represents the vehicle's wheel radius and G is the overall gear ratio between the motor and the wheels.

The throttle/brake demand is communicated directly from the control position in the simulator to the motor controller. This throttle / brake command will cause the motor to respond which results in a speed measured by the dynamometer. The controller manages the throttle and brake inputs and allows for tweaking of input response. Based on the above model a new torque value is calculated and sent to the dynamometer. The start torque is derived directly from the rolling resistance since this is the only force at no speed.

The power applied to the motor will cause it to work against the torque applied by the dynamometer. The speed of the resultant rotation will be recorded and used to update the dynamic model and will be converted to vehicle speed which will be communicated back to the simulator.

System Implementation

Implementation of the system is underway. The following activities have been completed:

- Communications between the simulator and the dynamometer control systems is achieved via a TCP connection operating over a Local Area Network.
- Dynamometer control is achieved using National Instruments' PCI-MIO-16E-4 real-time data acquisition card. This card operates its own operating system and Virtual Instruments (VI's) can be downloaded to the card through LabVIEW 7 RT.
- Bi-directional communication has been achieved with 2 computers running LabVIEW software. The first computer contains the I/O card and runs the real-time VI. The second computer runs as a TCP/IP server

and sends required data to the first computer and receives the data sent from the first computer. This Setup allows simple testing and improves development speed.

- Communications between Simulator and Dynamics computer have been tested and validated

The Dynamic Model has been implemented in LabVIEW as a VI running on the I/O card. A screenshot of the interface where the model properties are configured is shown in figure 5.

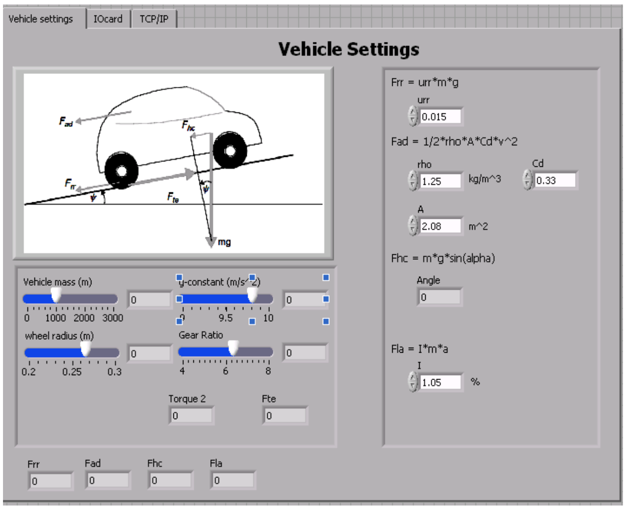

Fig.5. Dynamic model screenshot

Conclusions and future work

The benefits and difficulties involved in connecting a driving simulator to an EV hardware test system to allow human control of hardware tests have been described. Work is ongoing to achieve successful integration and proof of the concept of human-in-the-loop hardware testing. Once the concept is proved it will be necessary to develop suitable test strategies to ensure the maximum benefit is achieved from the system.

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