School of Mechanical Engineering

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Instrumentation for the REV Project, an Electric Vehicle Conversion

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Dear Professor Bush

I am pleased to present this thesis entitled "Instrumentation for the REV Project, an Electric Vehicle Conversion" as partial fulfilment of the requirements for the degree of Bachelor of Engineering (Mechatronics).

Yours sincerely

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10408511

Abstract

In an age of soaring fuel prices and growing concern over climate change, interest in electric vehicle (EV) design and research is mounting. As EV battery and propulsion technologies continue to improve and costs decrease, owning a vehicle which does not emit pollution at the point of use will become increasingly viable for environmentally conscious vehicle owners. One option for car enthusiasts is to convert a combustion engine vehicle to electric drive. The conversion of a 2008 Hyundai Getz to electric drive has been undertaken by students at the University of Western Australia as part of the Renewable Energy Vehicle (REV) project. In an EV conversion, new instruments need to be designed to sample and display crucial EV specific parameters such as battery voltage, current and state-of-charge to the driver. For the UWA vehicle, this data will be logged by on on-board controller for performance analysis.

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The whole REV team, especially Rohan, Steve and Ewan, for their help when help was needed, their patience and their company during the many hours spent in G.50

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Table of Contents

List of Figures

List of Tables

List of Acronyms

AC, DC	Active Current, Direct Current
ADC	Analog to Digital Converter
ADR	Australian Design Rules
CAN	Controller Area Network – communication protocol used in vehicles
EV	Electric Vehicle
GPS	Global Positioning System
GUI	Graphical User Interface
ICE/IC Engine	Internal Combustion Engine – typical petrol engine
LCD	Liquid Crystal Diode – Display screen
PWM	Pulse Width Modulation
REV	Renewable Energy Vehicle
RPM	Revolutions Per Minute
SOC	State-of-Charge
USB	Universal Serial Bus
UWA	The University of Western Australia

1 Introduction

The University of Western Australia's (UWA) Renewable Energy Vehicle (REV) Project aims to demonstrate the viability of electric vehicles and generate public interest in the field. The 2008 REV project was coordinated by Associate Professor Thomas Bräunl under the Faculty of Electrical, Electronic and Computer Engineering. The project involved students from a broad range of engineering disciplines working together to complete the conversion of a 2008 Hyundai Getz to electric drive.

While it would be ideal to custom design and build the entire electric vehicle, getting this road registered would be a complicated affair because of the comprehensive licensing rules, mainly concerning safety, as set out in the Australian Design Rules (ADR) (Australian Government, 2006).

The driver of a vehicle should be aware of the state of their system and be informed as to any event that could compromise their safety. This thesis outlines the design and implementation of a system to collect and process essential vehicle data in the converted Hyundai Getz. In a battery electric vehicle, system data additional to that typically displayed on the instrument cluster of an internal combustion engine (ICE) vehicle needs to be monitored and communicated to the driver. The traction battery current and voltage are examples of important electric vehicle properties that are not relevant to ICE vehicles.

As part of the project, the Hyundai Getz has been fitted with an EyeBot M6, an embedded controller developed at UWA. The latest generation EyeBot includes an LCD touch screen for displaying information to the vehicle driver and may be extended to display camera images and GPS maps. The EyeBot is primarily used in this project for the collection, display and logging of vehicle data.

Although there are many commercially available instruments for displaying electric vehicle information, such as the TBS battery monitor installed in the Getz (Appendix A), the EyeBot controller offers the versatility to collect a wide range of system parameters, display a user-friendly custom interface and allow data logging for analysis. Additionally, it will easily allow future students working on the project to make improvements and additions to the vehicle's systems and displays.

The 2008 REV Project provides a foundation from which future engineering students will be able to launch further investigations into electric vehicle technologies.

1.1 Electric Vehicles

The first electric cars were commercially available over 100 years ago. In recent years, major car manufacturers have released very few battery electric vehicles into the market, quoting prohibitive costs and insufficient demand. The documentary "*Who Killed the Electric Car*" (Paine, 2006) accuses oil companies, car companies and government of being some of the influences prohibiting the development and commercialisation of electric cars in the United States of America. The limited availability of electric vehicles means converting an IC engine to electric drive may be the easiest option for car enthusiasts wishing to own an electric vehicle.

With do-it-yourself guides readily available and a wealth of conversion tips, examples and products on-line, electric vehicle conversions have become a feasible undertaking for individuals, groups and private companies. As battery and propulsion technologies improve, the cost of conversions will decrease and the vehicle range and performance will improve.

1.2 The REV Project

In early 2008, The University of Western Australia's Renewable Energy Vehicle project (REV) was re-launched, challenged with converting two cars from internal combustion to pure electric drive. The first car, a 2008 Hyundai Getz was to be converted with economy driving the design decisions.

Despite economy being a major concern, it was still desired that, after the conversion, the vehicle should retain all the modern conveniences it was originally equipped with. As such, additional systems needed to be installed to power electric steering and air-conditioning units that previously ran off the drive shaft.

Early in 2008, the engine and fuel tanks of the Getz were removed and the conversion begun.

An Advanced DC FB1-4001A 9.1 Series Wound DC motor was chosen to drive the vehicle and a Curtis 1231C-8601, 96-144 Volt, 500 Amp Controller installed in conjunction.

The batteries, remnants of an earlier manifestation of the REV project, entailed 45 ThunderSky Lithium Ion LFP90AHA batteries with a nominal voltage of 3.2V, rated capacity of 90AHA and nominal current of 270A.

A Zivan NG3 Battery charger was installed to charge the batteries, allowing plug in to any average household electrical socket and a ThunderSky battery balancing system added for battery protection.

The future scope of the project includes installing an array of solar panels to the roof of the Electrical Engineering building with the energy produced being channelled back into the grid. The solar energy will be monitored and compared with the energy consumed by the car, the objective being to deliver more electricity to the grid than is drawn when charging the vehicle's 45 lithium-ion batteries. In addition, a second hand Lotus Elise, will be converted to electric drive with performance objectives in mind.

1.3 Instrumentation

The driver of an electric vehicle requires some additional feedback to that which is traditionally displayed on the instrument panel of an ICE vehicle. EVAustralia recommends RPM, voltage and current meters as the bare minimum additions to the instrumentation of electric vehicle conversions. The voltage level tells the driver how much "fuel" is left in the batteries, while the current level gives the driver an indication of how fast that fuel is being used. A tachometer (indicating engine RPM) is important for efficiency and performance, whilst preventing over-revving of the engine.

In the Hyundai Getz, the original instrument cluster, shown in Figure 1.1 below, was dominated by the speedometer and the tachometer.

Figure 1.1 - The Hyundai Getz Instrument Cluster

The panel also included an odometer and fuel gauge, along with various system indication lights. The operation of the speedometer and odometer were not affected by the conversion, however, removal of the combustion engine and fuel tank meant the tacho (engine RPM) and fuel gauge signals to the dashboard no longer existed.

For the Getz, it was desired that the new instrumentation should, as much as possible, appear to be an integrated part of the vehicle. For this reason, it was decided that the existing gauges should be utilised, supported by an LCD touch screen and a TBS Electronics Battery Monitor. “Fuel” no longer being a relevant concern, it was decided that the fuel gauge should instead be used to indicate the electric vehicle equivalent, the state of charge (SOC) of the batteries. A new tacho was also installed to replace the function formerly served by the crankshaft position sensor.

The EyeBot controller will process the battery pack voltage and current readings to produce a meaningful SOC output by integrating the current over time. This output will be used to drive the original fuel gauge as well as being logged by the EyeBot and displayed on the LCD screen.

The Eyebot controller will also be used to monitor crucial safety signals, especially important in an electric vehicle, considering the high currents and voltages involved (O’Brien, 1993). In addition to monitoring the health of these safety systems, and sampling instantaneous battery voltage and current, the Eyebot will collect GPS coordinates, engine RPM and vehicle speed signals for display and logging. Figure 1.2 below lists the signal inputs and outputs to the Eyebot controller for the instrumentation.

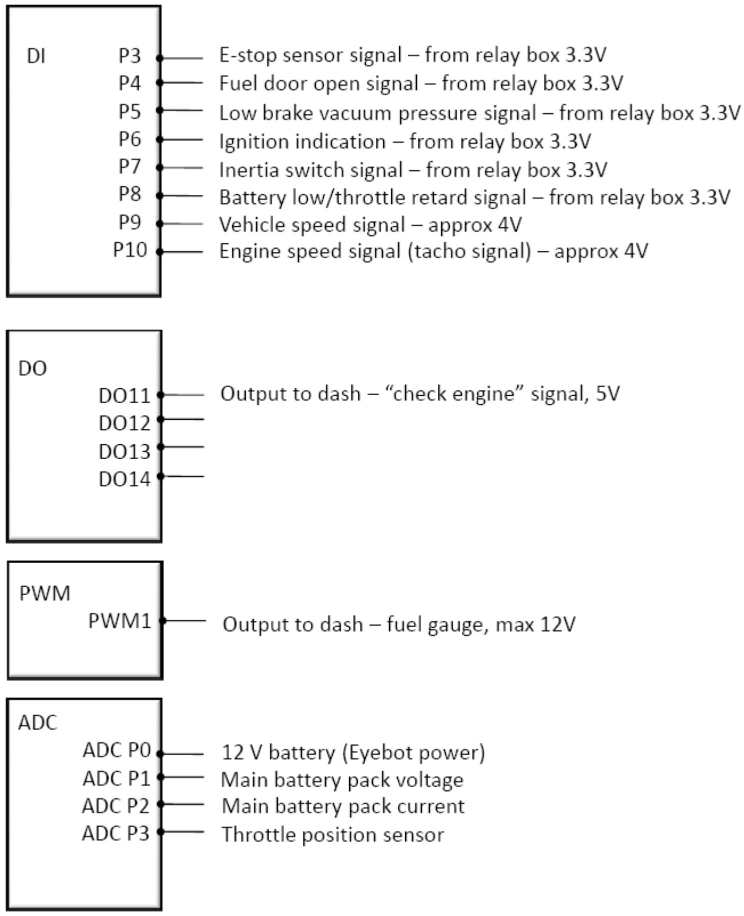


Figure 1.2 - Eyebot Controller Input and Output Pins for Instrumentation

1.4 Thesis Overview

This thesis discusses the collection, display and logging of vehicle data from the Hyundai Getz electric conversion. The thesis may be summarised as follows:

Chapter 2 - discusses the current state of the art concerning electric vehicles and EV instrumentation and the merits of previously conducted research in the area.

Chapter 3 - discusses the various signals monitored by the on-board controller installed in the Getz.

Chapter 4 - presents the resulting system of data collection and display.

Chapter 5 - outlines some conclusions and details potential further work in the area.

2 Background

For this project the EyeBot controller will be used to calculate the state-of-charge of the batteries and to control signals that indicate system conditions to the driver. In 2004, Ibanez and Dixon implemented a battery monitoring unit using a microcontroller and displayed the information to the driver on and LCD touch-screen installed above the front window. The refresh rate of their system was good enough for display purpose but would not have been sufficient as a control system. Their system displayed the voltages of each individual battery, useful for ensuring the batteries remain balanced but not fully representative of the state of charge of the batteries

To calculate the state-of-charge (SOC) of the batteries, an algorithm will have to be computed by the microcontroller. One of the simpler methods for calculating the SOC takes the average of voltage and current over the past few minutes and uses that with an interpolated look-up table of discharge curves to determine the approximate state of charge [6]. The coulomb counting method is discussed in various papers (Chiasson and Vairamohan, 2005; Kim, 2008; Caumont et al, 2000) which mostly discuss its limitations and suggest other methods for approximating the state of charge. Such methods discussed included fuzzy logic, Kalman filters, measurements of cell impedance and equivalent circuit analysis of charge and discharge curves (Hua et al, 2007).

Other systems using microcontrollers to control vehicle auxiliary systems often have special data buses or distributed control to reduce cabling and power losses (Ibanez and Dixon, 2004). Complex wiring can take up valuable space and weight in a vehicle. Auxiliary systems control involves many data inputs and outputs, and these are steadily increasing as consumers demand more safety and luxury features (Azzeh and Duke, 2005). Such features include airbags, traction control and entertainment systems.

Safety interlocks, alarms and indicators are very important on an electric vehicle – especially considering the high voltage and current capabilities and the safety hazards associated with maintenance and charging (O'Brien, 1993). As per regulations for road registering an EV conversion, there needs to be an emergency kill switch within easy reach of the driver with a mechanical disconnecting mechanism. Another safety interlock requires the charge door to be closed before the high voltage circuit can be engaged. This prevents a drive from driving away while still plugged in to the AC mains supply.

3 Instruments

3.1 Battery State-of-Charge

In simple electric vehicle conversions it could be considered sufficient to display the battery pack voltage as an indication of remaining battery capacity, usually read when the vehicle is at rest. Voltage-discharge curves differ however, depending on the current draw, meaning that voltage alone does not give a comprehensive indication of battery charge. Additionally, the relationship is not linear with voltage remaining relatively constant during a large proportion of the battery discharge. The graph of battery voltage (V) versus battery capacity (in Amphours) in **Figure 3.1** below illustrates the voltage-capacity curve for a single ThunderSky lithium ion 90AHA battery, such as those used in the Getz. The three curves represent different current draws, as labelled.

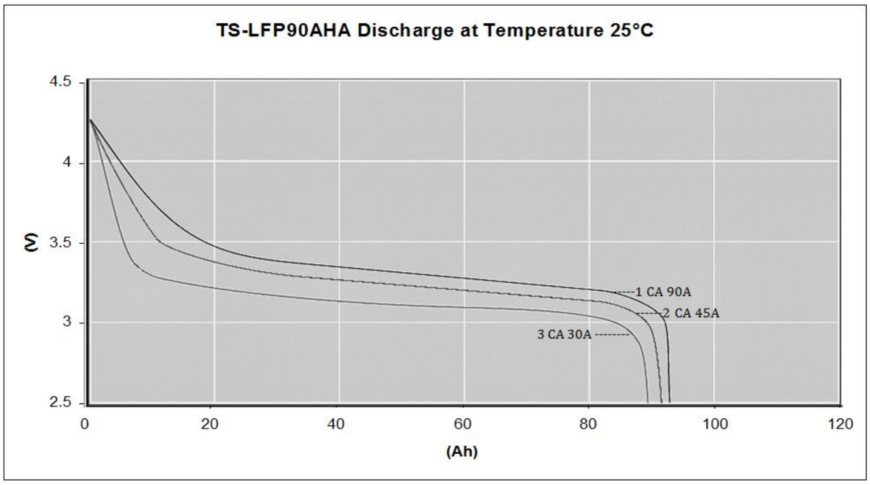


Figure 3.1 - Getz battery discharge characteristics of a single cell (APPENDIX B)

The State of Charge (SOC) of a battery is its available capacity expressed as a percentage of its rated capacity. REFERENCE? One method for calculating the SOC of a battery pack is commonly called "coulomb counting". This involves integrating the current draw over time to approximate the Amphours discharged or the Amphours replenished when charging.

3.1.1 Battery State-of-Charge Approximation

The method proposed for estimating battery state-of-charge is the coulomb counting method. The coulomb counting method (Chiasson and Vairamohan, 2005; Kim, 2008; Caumont et al, 2000) involves integrating current over time to approximate the number of Amphours discharged under load or recovered when charging.

The value of the integrated current is subtracted from the battery nominal capacity, 90Ah for the lithium ion batteries used in the Getz and expressed as a percentage of the capacity, the algorithm can be summarised by equation (3.1) , where *SOC* represents the stat-of-charge, $Q(t_0)$ is the battery capacity in Amphours at the beginning of the monitoring period, Q_{full} represents the capacity of the battery at full charge, and the current, i, is integrated from the beginning of the monitoring period

$$SOC(t) = \frac{Q(t_0) - \int_{t_0}^{t} i(t)dt}{Q_{Full}} * 100 \tag{3.1}$$

Hua et Al, 2007, proposed a residual capacity estimator for lead acid batteries. The authors use curve-fitting to essentially assign a weight to the current being integrated based on the discharge rate. One method of approximating this approach would be a look-up table of weightings. This would also be useful for adjusting the algorithm when recharging the batteries to account for the fact that the batteries are less than 100% efficient at recovering charge. Calculating these weights for the Lithium Ion batteries used in the Hyundai Getz would require extensive testing or access to more comprehensive battery specifications than have until now been made available.

One of the criticisms of the coulomb counting method is that it does not converge to the true value but accumulates errors. A “synchronise” option on the EyeBot, to be selected on the GUI manually, allows the state-of-charge algorithm to be reset to full at the end of every complete charge cycle. This prevents the accumulation of errors. This synchronisation could be prompted by the EyeBot when charging is detected.

3.1.2 Reading Voltage

The battery pack consists of 45 batteries of a nominal 3.2 Volts, giving an overall pack voltage rated at a nominal 144V. As the individual batteries can range between 2.5 and

4.25 Volts, the overall pack voltage has a potential range of 112.5 to 191.25V. This value is pre-scaled down by a factor of ten using a commercial pre-scaler. To measure this value using the Eyebot, these voltages need to be further reduced. This can be done using a voltage divider. To make full use of the analogue to digital converter range, thereby increasing measurement accuracy, a differential amplifier could be used to offset the voltage signal so that the 0 to 5V input range represents the full output range of 112.5 to 191.25V.

The EyeBot utilises 10 bit analogue to digital converters (ADCs). If the 0 to 5V input range were to represent (through signal scaling) the full range of battery voltage, the resolution could be calculated by the equation 3.2 below,

$$\mathrm{Re}s = \frac{(Max\_input - Min\_input)}{2^{number\_of\_bits}} \tag{3.2}$$

$$= \frac{(191.25 - 112.5)}{2^{10}}$$

$$= 0.0769V$$

In this case, the smallest resolution achievable for the battery pack voltage would be 0.077 Volts. This is what a one bit change of the digitalised signal would represent. For simplicity, it was decided to use the EyeBot's inbuilt voltage divider, requiring only the addition of a single external resistor. The best resolution that can be obtain, with 5V representing the maximum of 191.25V, was calculated using equation (3.2) with the minimum voltage this time being equal to zero,

$$\mathrm{Re}s = \frac{(Max\_input - Min\_input)}{2^{number\_of\_bits}}$$

$$= \frac{(191.25 - 0)}{2^{10}}$$

$$= 0.1867V$$

The best resolution achievable in this case is 0.187 Volts, more than twice the optimal case but still an acceptable resolution.

In order to scale the voltage reading such that 191.25V is represented by a 5V input to the ADC, the correct value resistor must be chosen.

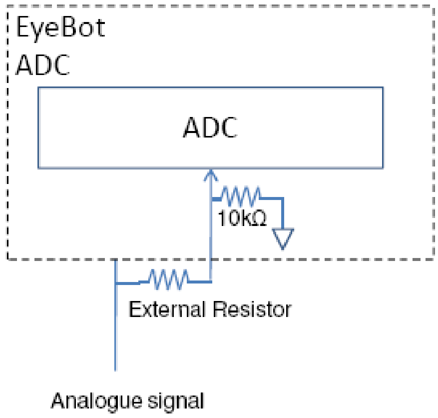
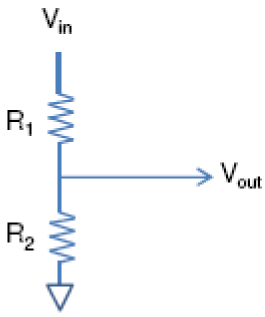


Figure 3.2 – Simplification of the ADC voltage division capacity

After pre-scaling, the battery pack voltage of 191.25V would read as approximately 19.125V. To convert this to 5V, voltage divider principles need to be applied. The standard case and general equations are depicted below where R_2 corresponds to the EyeBot internal 10kΩ resistor and R_1 is the required external resistor.



$$V_{out} = V_{in} \cdot \frac{R_2}{R_1 + R_2}$$

Figure 3.3 - Standard voltage divider

The value of the external resistor can now be calculated.

$$V_{out} = V_{in} \cdot \frac{R_2}{R_1 + R_2}$$

$$5 = 19.125 \frac{10k}{10k + R_2}$$

$$R_1 = 10k * \left(\frac{19.125}{5} - 1 \right)$$

$$R_1 = 28.25k\Omega$$

Precise measurements of the pre-scaling device and the voltage divider resistances should be made to determine the overall factor by which the signal has been scaled.

3.1.3 Reading Current

The battery pack current is calculated by measuring the voltage across a 500A, 50mV shunt resistor. The voltage difference across the terminals is very small and needs to be amplified before being sampled by the Eyebot. Because of this amplification, electrical noise is a major concern and the wires across the shunt should be a twisted pair to avoid the effect of noise.

The diagram in Figure 3.4 below shows the setup for the current sensor. The voltage measured across the shunt resistor falls within the range of ±50mV, depending on whether the batteries are being charged or discharged. A gain of 50 will result in an output signal of ±2.5V. With a single voltage supply, the reference voltage needs to be raised to 2.5V to allow the full range of inputs to be amplified. The output voltage will then be 2.5 ±2.5V.

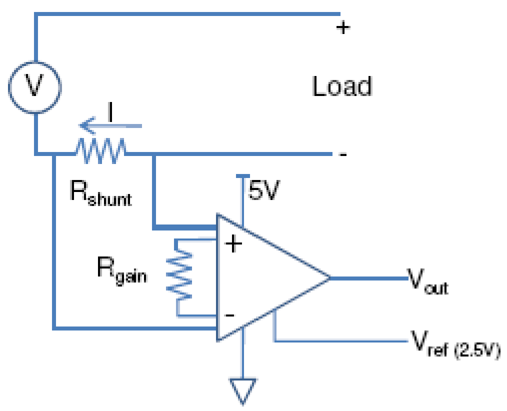


Figure 3.4 - A current sensor

In this way, the full current range of -500A to 500A is scaled to between 0 and 5V. The resolution of the current measurement can be calculated using equation

$$\mathrm{Re}\,s = \frac{(Max\_input - Min\_input)}{2^{number\_of\_bits}} \qquad (3.2),$$

$$\mathrm{Re}\,s = \frac{(Max\_input - Min\_input)}{2^{number\_of\_bits}}$$

$$= \frac{(500-(-500))}{2^{10}}$$

$$= 0.976A$$

The finest resolution available for current is just under 1A. One of the requirements for a reasonable state-of charge estimation using the coulomb counting method according to Kim, 2008, is the use of an accurate current sensor. The desired accuracy is not quantified by Kim. With the system fully installed and programmed the estimation error under various conditions may be investigated and the effect of the current sensor accuracy on the approximation assessed.

3.1.4 Fuel Gauge

In an electric car the state-of-charge of the batteries is equivalent to the amount of fuel left in a normal petrol engine. As such, utilizing the existing fuel gauge to display the battery state-of-charge creates a natural and easily interpreted reference for the vehicle driver.

The fuel sender in normal petrol engine cars consists of a float with a variable resistor mounted to it. The fuel sensor electrical circuit can be modeled as below in Figure 3.5.

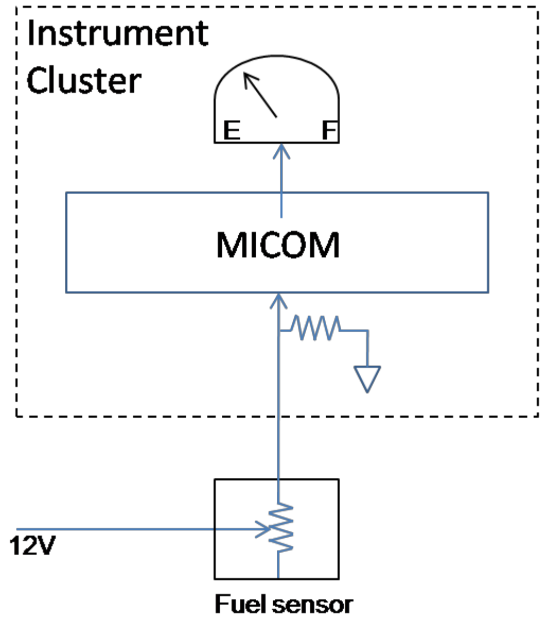


Figure 3.5 - Fuel gauge operation

The entire fuel sender assembly can be replaced by a voltage source to manipulate the position of the gauge. This voltage can be generated by the Eyebot controller using pulse width modulation.

To determine the voltages required for desired positions of the fuel gauge, a voltage generator was used to move between 0 and 12 volts, recording the voltages that corresponded to the eight readily identified markers between empty and full on the gauge.

The results are shown in figure 3.6 below

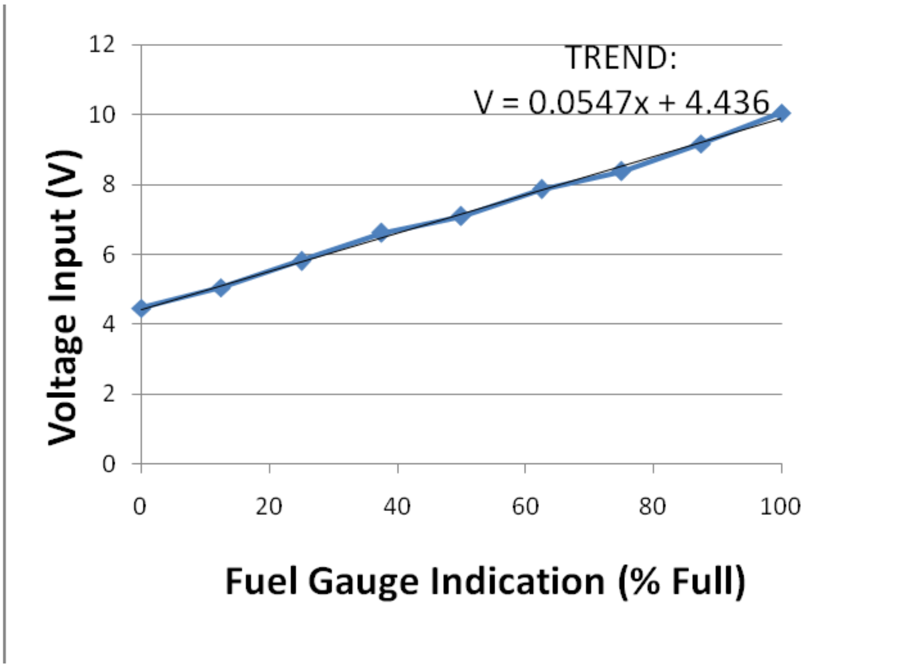


Figure 3.6 -Voltage input to existing fuel gauge for given fuel level (or SOC) indications

From figure 3.6 we can see that there is a linear relationship between the supplied voltage and the fuel gauge indication. This can be modelled by the relationship ine equation 3.3 below

Relationship:

$$V = 0.0547 * SOC + 4.436 \tag{3.3}$$

This relationship can be used by the Eyebot to determine the voltage output to the gauge based on the current state of charge of the batteries.

As with the fuel in a car, this value changes slowly so it is not necessary to update the PWM output on every scan of the control program. This decision would left to the programmer depending on the speed and computing requirements of the overall program.

The Eyebot controller does not have any analogue outputs. As such, it is necessary to simulate a DC voltage using pulse width modulation (PWM). PWM involves modulation of the duty cycle of a signal. By switching the voltage with an appropriate duty cycle, the average voltage across that cycle approximates a DC voltage.

The fuel gauge is attached to an Eyebot motor output which produces square waves with peaks at 12V. Thus, by varying the duty cycle between 0 and 100% voltages between 0 and 12V can be simulated according to a linear relationship.

3.2 Speed Sensors

The results of investigation into the Hyundai Getz electrical system have enabled the REV team to connect to and manipulate the original dashboard gauges. The original speed signal has also been tapped into for analysis by the EyeBot controller. A new instrument needed to be installed to generate engine speed information.

3.2.1 Tachometer

With the removal of the crankshaft position sensor, the Hyundai Getz required a new method for acquiring the engine speed information.

A hall-effect sensor was attached to the end of the electric motor. Hall Effect sensors for measuring motor speed encompass a rotating component and a stationary component. The rotating target rotates with the motor shaft. Magnets in the rotating target create a magnetic field across the Hall Effect sensor as they pass across the face of the stationary probe. This magnetic field, perpendicular to a flowing current, will create a charge differential across the Hall element. This effect is utilised to generate voltage pulses on the signal line of the instrument, one pulse for every magnet in the sensor on every revolution of the motor shaft.

The tachometer used for the Hyundai Getz was experimentally proved to have 4 magnets, creating 4 pulses per revolution.

The 2008 Hyundai Getz was significantly different, electrically, than the 2003-2007 models for which workshop manuals were available. Difficulty accessing the pertinent specifications meant that much necessary information needed to be verified experimentally. The tachometer gauge was tested using a voltage generator, generating square wave signals at varying frequencies and recording the position of the tachometer needle for each frequency. The results for 50, 75 and 100Hz were considered sufficient confirmation of the suspected operation of the tachometer. The results in table 3.1

below verify that the tachometer displays a reading for engine RPM that is half the input frequency.

Square-wave Input Frequency (Hz)	50	75	100
Square-wave Input Frequency (RPM)	3000	4500	6000
Tachometer Indication – approx. (RPM)	1500	2300	3000

Table 3.1 - Tachometer readings for given input frequencies

The maximum rotational speed of the motor is purported to be 4200 rpm. The signal from the Hall Effect sensor at 4 pulses per revolution would read 8400 rpm if connected directly to the dashboard gauge. The gauge does allow readings of up to 8000 rpm however, it would be easier and more intuitive to a user to leave the numbering in the current configuration.

To convert from 4 pulses per revolution to the 2 pulses per revolution required to obtain the appropriate reading on the original gauge, a JK flip-flop was used to effect a frequency-divided-by-two algorithm.

The simplest flip flop that will achieve this result is a Toggle or T flip-flop. By linking the JK inputs together as shown in figure 3.7 below, the JK flip-flop behaves in the same manner as a T flip-flop

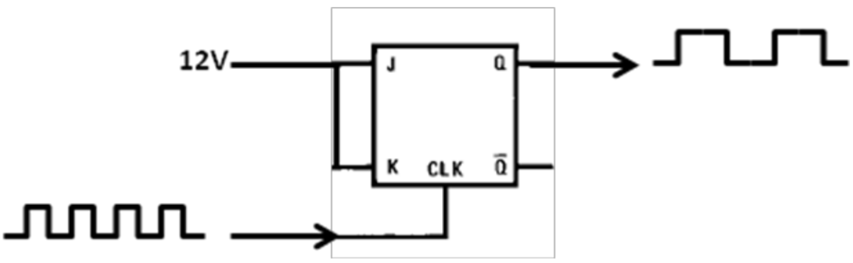


Figure 3.7 - JK flip flop, frequency divided by 2 feature

The timing diagram in figure 3.8 below shows the output for a rising edge triggered clock. It can clearly be seen that the frequency of the signal has been halved.

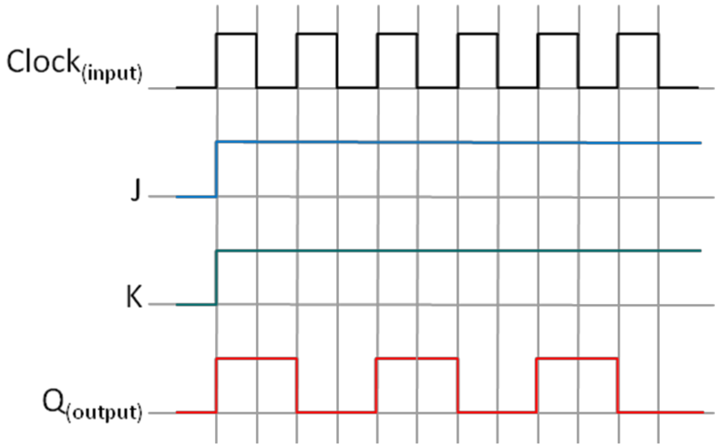


Figure 3.8 - Flip-flop frequency/2 timing diagram

3.2.2 Vehicle Speed Sensor

From the workshop manual specifications, the speed sensor emits 4 pulses per revolution, where 637rpm at 4 pulses per rev indicates 60km/h.

From this data, a relationship between frequency and speed can be calculated. In equation 3.4 below, *x* is a constant, the coefficient of conversion, *f* is the frequency of the sensor signal (Hz) and *v* is the vehicle speed,

$$x * f = v \quad \textbf{(3.4)}$$

The Getz specifications are inserted into the equation to calculate *x*,

$$x * 637*4/60 = 60$$

$$x = 1.413 \quad \textbf{(3.5)}$$

3.2.3 Distance Counter

The speed sensor pulses-to-speed relationship can also be used to calculate the distance travelled. As at 60km/h, the car travels 1km in 1 minute and counts 637*4 pulses in that minute, every time a pulse counter registers 637 pulses we can conclude that the vehicle has travelled 0.25km.

This distance data can be used in conjunction with the battery state-of-charge to estimate the average fuel economy in km/Ah of the vehicle. This value is constantly updated and can be used to calculate a“distance to empty” estimation based on the number of Amphours remaining, as estimated by the SOC approximation.

3.3 Dashboard Indicators

With the removal of the IC engine, dashboard indicators such as the “check engine” signal and the temperature sensors become redundant. Without the normal engine components and signals present, the “check engine” indicator is constantly lit. To remove this distraction and allow future use of this signal, the signal line from the ECU was cut and the input redirected to be controlled by the EyeBot. The signal to illuminate the “check engine” indicator is a voltage of 12V. The output from the Eyebot digital output pins has a maximum of 5V. To overcome this difference in voltages, a 5V switching relay has been utilised. The figure 3.9 below shows how the relay is employed.

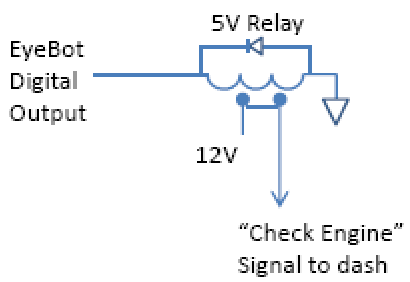


Figure 3.9 - "Check Engine" relay

The temperature indicators are not currently being utilised. There are both blue and red indicators to signify either cold or hot temperatures but there is no useful temperature scale.

The low fuel light operates in line with the fuel gauge. There is not a separate signal to illuminate the low fuel light, when the fuel level is below the calibrated empty point, the low fuel light illuminates. To operate the low fuel light, the fuel gauge needs to be driven to empty.

From figure 3.6, the graph of, fuel gauge indication versus voltage, it can be seen that the fuel gauge will read empty for voltages below approximately 4.5V.

3.4 Safety

Safety interlocks, alarms and indicators are very important on an electric vehicle – especially considering the high voltage and current capabilities and the safety hazards associated with maintenance and charging (O'Brien, 1993). One of the functions of the EyeBot is to monitor the state of these safety signals. Safety critical systems developed independently of the EyeBot. The Eyebot is purely an observer.

Australian design rules dictate that electric vehicles must have and emergency stop button within easy reach of the driver at all times that will create a mechanical break in the high voltage system. In addition to this it is desirable to have a method of automatically cutting off power in the event of a crash. To cover the latter safety requirement, an inertia fuel cut-off switch has been installed in the Hyundai Getz. The inertia switch makes up part of a set of relays that must be closed before the secondary contactor for the 144V system is closed. The EyeBot receives six digital signals from this relay box.

Table 3.2 below lists the Eyebot I/O signals

Digital Inputs	
DI 1:	E-stop sensor signal – 3.3V from relay box
DI 2:	Fuel door open signal – 3.3V from relay box
DI 3:	Low brake vacuum pressure – 3.3V from relay box
DI 4:	Ignition indication – 3.3V from relay box
DI 5:	Inertia switch signal – 3.3V from relay box
DI 6:	Battery low/ throttle retard signal – 3.3V from relay box
DI 7:	RPM signal from newly installed tacho – 4 pulses/rev
DI 8:	Speed signal from original speed sensor – 4 pulses/rev
Digital Outputs	
DO 1:	Output to "Check engine" light on dash
Pulse Width Modulated (Motor) Outputs	
PWM1:	Signal to drive original fuel gauge

Analog Inputs (10 bit ADC) AI 1: Battery pack voltage AI 2: Battery pack current (voltage signal – across shunt) AI 3: Throttle position sensor (AI 4): 12V aux battery (voltage monitored and used to power Eyebot)
Mic Input Future Expansion (voice commands)
Mic Output Used for warning system.
USB Ports USB 1: GPS USB 2: Memory stick for data logging

Table 3.2- EyeBot I/O

The sensor signals into a relay box (at 12V) must all be healthy before the high voltage lines are connected to the engine by the secondary contactor. The relay box converts these signals to 3.3 volt digital inputs to the EyeBot for indication to the driver. These safety interlocks required the installation of a fuel door open switch to prevent operation while the vehicle is charging, the inertia kill switch and a low pressure signal from the new brake pump. The battery low/throttle retard signal comes from the battery management system to indicate critically low battery voltage.

4 Results

The majority of the Hyundai Getz instrumentation has been installed and the vehicle is awaiting licensing. Figure 4.1 below shows a complete schematic of the signals being monitored by the EyeBot controller. The installation of new instruments such as the tachometer, inertia switch and "fuel door open" indicator will allow the driver to remain aware of the state of their vehicle.

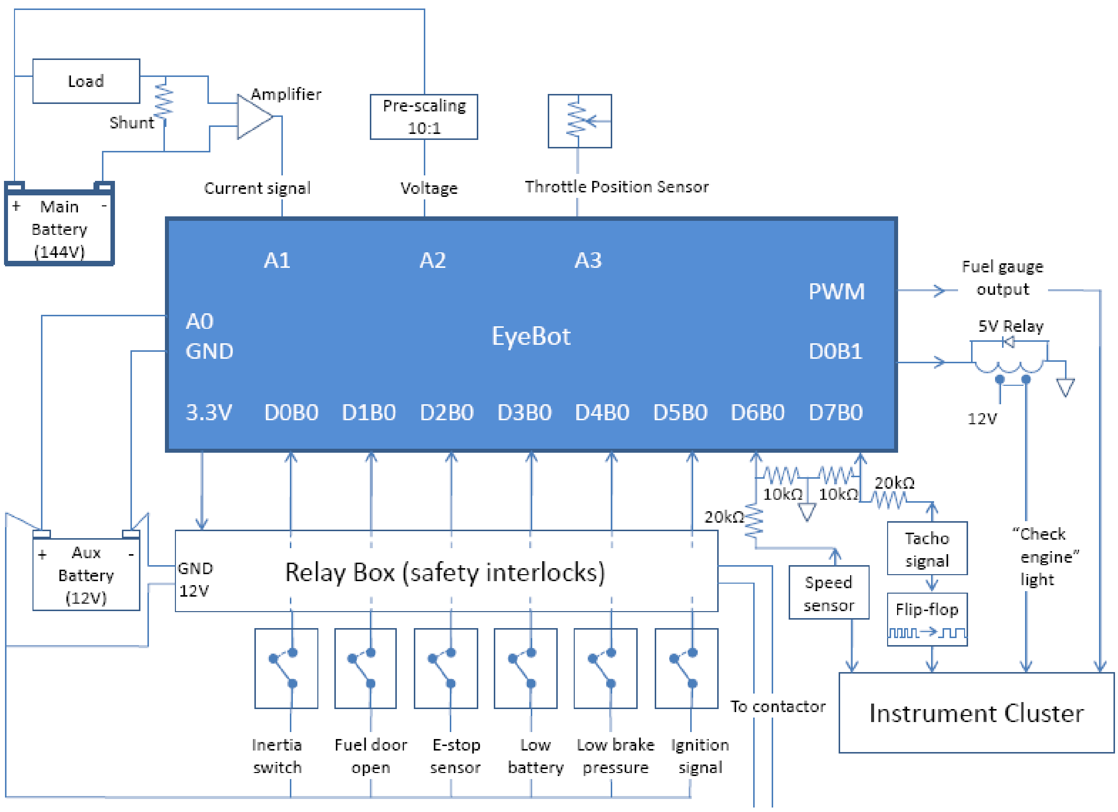


Figure 4.1 - Complete Eyebot data collection schematic for the instrumentation

Currently the EyeBot data acquisition program for the Hyundai Getz system is only able to sample and store data at a rate of 9Hz. This is significantly inadequate if the EyeBot is intended to register pulses from the tachometer at rates of up to 140Hz. One alternative would be to use a frequency to voltage circuit to monitor the vehicle and engine speed signals. However, this would require the capacity for more analogue inputs.

To extend the data acquisition capacity of the EyeBot, a data acquisition card could be used, connected to the EyeBot by USB or serial cable. Another consideration for acquiring existing vehicle data would be to investigate the vehicle's Controller Area Network (CAN) communications. CAN is a standardised protocol for in-vehicle communications (Azzeh and Duke, 2005).

Figure 4.2 below shows the EyeBot signals joining at two connectors to facilitate the easy removal and replacement of the EyeBot module. The tacho and speed signal voltage dividers and check engine relay project box is also shown.

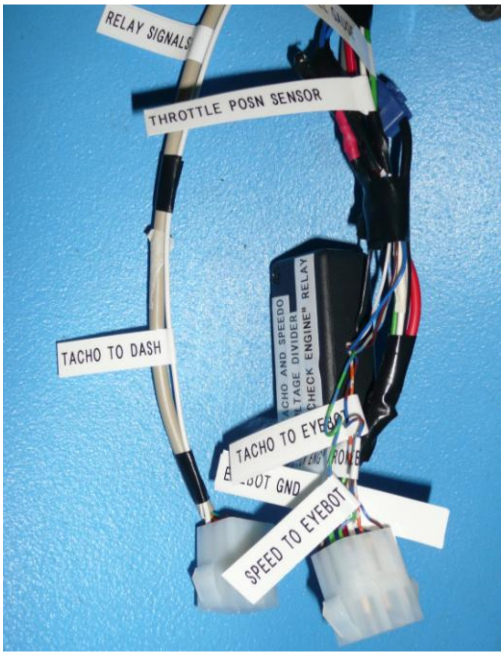


Figure 4.2 - Signal collection and scaling

The flip-flop frequency divider for the tachometer signal was developed separately to other electric circuit components. Combining the two modules would require less wiring and occupy less space. The design in figure 4.3 below shows how the modules could be combined.

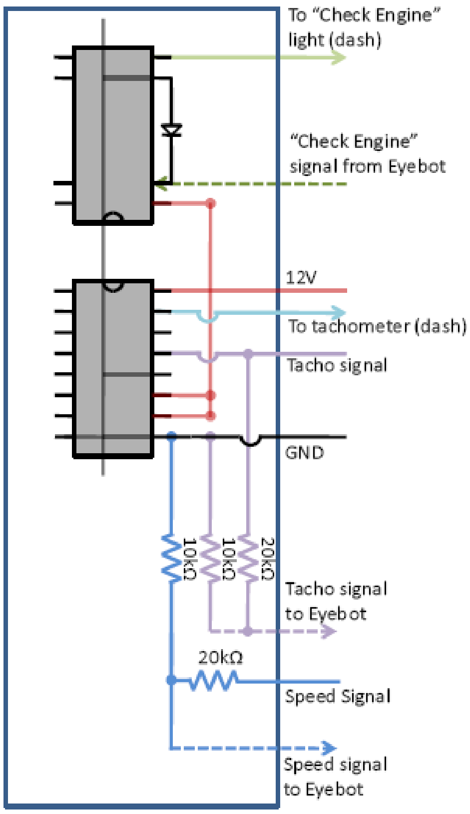


Figure 4.3 – Integrated circuit for tacho, speed and "check engine" signals

This circuit board could be further extended to include the current sensor amplifier circuit.

The systems for data collection in the Hyundai Getz have been implemented and await on-road testing under varying conditions. All systems were designed keeping in mind the rough conditions that car instrumentation undergoes. Most of the new instruments bought for the vehicle were specially designed for vehicle applications.

5 Conclusions and Further Work

In an electric vehicle conversion, appropriate instrumentation needs to be implemented so that the driver is aware of the state of his system and made aware of any problems that are affecting the safety or performance of the vehicle. Crucial system parameters are battery voltage, current and state-of-charge, vehicle speed, engine speed, and distance remaining before battery recharge is required. Having connected these parameters, future students will want to gather vehicle data for analysis and to verify the accuracy, or otherwise, of the state of charge algorithm.

The vehicle data gathered as a result of the systems installed as part of this project will be useful for future students wishing to assess the performance and efficiency of the Hyundai Getz under a variety of driving conditions and serve as a basis for designing the information network for the Lotus Elise conversion.

6 References

Australian Government, Department of Infrastructure, Transport, Regional Development and Local Government, 2006, Third Edition Australian Design Rules, available on-line <http://www.infrastructure.gov.au/roads/motor/design/adr_online.aspx> [sited August 2008]

Azzeh, A. and Duke, R. 2005, CAN Control System for an Electric Vehicle. ENZCon 2005. Electronics New Zealand Conference. Manukau City, New Zealand

Bose, B. K. 1981. A Microprocessor-Based Control System for a Near-Term Electric Vehicle. Industry Applications, IEEE Transactions on Volume IA-17, Issue 6: pp. 626 – 631

Bowen, L.; Zarr, R. and Denton, S. 1994. A microcontroller-based intelligent battery system Aerospace and Electronic Systems Magazine, IEEE Volume 9, Issue 5: pp. 16 – 19

Caumont, O. And Moigne, P. 2000, Energy Gauge for Lead Acid Batteries in Electric Vehicles, IEEE Transactions on Energy Conversion Vol 15, 3 September 2000

Chiasson, J. and Vairamohan, B. 2005, Estimating the state of charge of a battery. Control Systems Technology, IEEE Transactions on Volume 13, Issue 3: pp. 465 – 470

Hua C. Et al, 2007, Design and Implementation of a Residual Capacity Estimator for Lead Acid Batteries, National Yunlin University of Science and Technology, pp.2018 - 2025

Ibáñez J and Dixon J, 2004, "Monitoring Battery System for Electric Vehicle, Based On 'One Wire' Technology", IEEE Vehicular Power Propulsion, VPP-2004, 6-8 October 2004, Paris, France

Keoun, B.C. 1995. Designing an Electric Vehicle Conversion. Southcon/95 Conference Record: pp 303-308

Kim, I. 2008, Non-linear State-of-Charge Estimator for Hybrid Electric Vehicle Battery, IEEE Transactions on Power Electronics Vol 23., 4 July 2008

Kitchin, C. and Counts, L. 2004, a designer’s guide to instrumentation amplifiers,2ND Edition, Analog Devices, USA

O'Brien, W.A. 1993. Electric vehicles (EVs): `a look behind the scenes' Aerospace and Electronic Systems Magazine, IEEE Volume 8, Issue 5: pp. 38 - 41

Oman, H. 1998. On-board energy and power management on electric vehicles: effect of battery type. Digital Avionics Systems Conference, 1998. Proceedings 17th DASC. The AIAA/IEEE/SAE Volume 2:pp. I43/1 - I43/6

Paine, C. 2006. Who Killed the Electric Car - documentary, Sony Pictures Classics, DVD

Thunder Sky, (2007), “Thunder Sky Lithium-Ion Power Battery Specifications”, Thunder Sky Energy Group Limited.

Webster, J.G. 1999, The Measurement, Instrumentation and Sensors Handbook. CRC Press

7 Appendices