DEVELOPMENT OF PURE ELECTRIC VEHICLE (EV) USING LEAD ACID BATTERY/ LI-ION BATTERY

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor (Hons.) of Electrical and Electronic Engineering

Faculty of Engineering and Science
UniversitiTunku Abdul Rahman

September 2011

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"DEVELOPMENT OF PURE ELECTRIC VEHICLE (EV) USING LEAD ACID BATTERY/ LI-ION BATTERY"** prepared by **LEOW ENG CHAI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Electronic and Communications Engineering (Hons.) at Universiti Tunku Abdul Rahman.

Approved by,

Signature : _______________________

Supervisor : Dr. Chew Kuew Wai

Date : ___________________

Specially dedicated to

my beloved parents and friends.

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ABSTRACT

The weakness of GPS navigation system coordinating with electric vehicle (EV) battery management system to estimate battery capacity always leads to inaccurate estimated range. A new system known as Contour Positioning System (CPS) had been introduced to improve the existing EV technology; it considers the contour condition along a selected route line. Total forces acting on a car during uphill condition are calculated and further related to current calculation to estimate battery capacity. An inclined plane experiment had been carried out to support the calculation method. Motor speed monitoring system had been done with a sensorless configuration, with a 16-bits microcontroller used as core controller. PIC24 with 10-bits ADC feature is used to convert analogue voltage to digital signal for further display on LCD display and transmitted to computer through serial ports. RS-232 communication protocol is used for serial communication between microcontroller and computer serial ports. Graphical User Interface of an EV intelligent monitoring system with data logging feature has been designed using Adobe Flash and the data reading from a text file is done using LoadVars method.

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LIST OF SYMBOLS / ABBREVIATIONS

EV	Electric Vehicle
ICE	Internal Combustion Engine
PM	Permanent Magnet
GPS	Global Positioning System
BMS	Battery Management System
CPS	Contour Positioning System
SOC	State of Charge
$F_{\parallel}$	Hill climbing force
F_{rr}	Rolling resistance force
F_D	Aerodynamic drag
C_d	Drag coefficient
A	Frontal area
v	Travelling velocity
ρ	Air density
T	Temperature
p	Pressure
h	Altitude above sea level
L	Temperature lapse rate
p_0	Sea level standard atmospheric pressure
M	Molar mass of dry air
R	Universal gas constant
g	Gravity constant
τ	Torque
G	Gear ratio
R_{wheel}	Wheel size
k_t	Torque constant
I	Current

RC	Radio-controlled
V_{supply}	Supply Voltage
$RPM_{no\text{-}load(max)}$	Motor's maximum no-load RPM
R_m	Terminal resistance
$I_{no\text{-}load}$	No-load current
k_b	Voltage constant
EMF	Electromotive force
MCU	Microcontroller
ADC	Analog-to-Digital Converter
RPM	Rounds-per-minute
GUI	Graphical user interface
EEPROM	Electrically Erasable Programmable Read-Only Memory

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CHAPTER 1

INTRODUCTION

1.1 Background

An electric vehicle (EV) is a car powered by an electric motor rather than a gasoline engine. From the definition, an electric car is converted from a gasoline-powered vehicle. The major difference between both vehicles is the way a car is powered; an electric vehicle is powered by electric motor and the conventional one is powered by gasoline engine. Another important component for an electric car is the rechargeable battery. There is a controller between the electric motor and the battery.

The early development of electric motive power was started since 1828 by Ányos Jedlik, the invention of a small scale model car powered by an electric motor. It was then followed by the invention of the first crude electric carriage powered by non-rechargeable primary cells by Robert Anderson from Scotland.

There was a significant weakness of electric motor powered vehicles at the early development stage, which is the lack of power. For example, the electric locomotive built by Robert Davidson in 1838 could only achieve a speed of 6km/hour. Electric vehicles were dominating the early automobiles field until the replacement by more powerful ICE (Internal Combustion Engine). Gasoline-powered vehicles were taking over the main role of transportation, globally.

It is the trend of modern world automobile industry where they are trying to bring back an old technology, make it new by further development, and that’s the introduction of an electric vehicle. The commercially available pure electric cars in the market nowadays include the Nissan's LEAF, the Chevrolet's VOLT, and the Tesla Roaster.

Figure 1.1: Nissan's LEAF

Figure 1.2: Tesla Roaster

Figure 1.3: Chevrolet's VOLT

1.2 Advantages of Electric Vehicle

➢ *Great Performance*

The electric car is silent, as compared to a conventional gasoline-powered car which is using an internal combustion engine (ICE).

➢ *Reduce greenhouse gases emission*

The most significant difference between an EV and a conventional gasoline-powered car is that an EV does not produce emissions. Hence it does not contribute to the greenhouse gases emission which leads to the depletion of ozone layer.

There are many people pointing that the charging of EV battery will also create emission at the power station; but it actually depends on the power source generating technology. Other than coal power plant that is utilizing fossil-fuel, there are some alternative power sources such as hydroelectricity, solar panel and wind farms.

As comparison, a conventional gasoline-powered car will produce much higher ratio of greenhouse gases. An EV produces only 5% to 10% of the emissions of an ICE per mile travelled.

- *Low cost (On the road)*

Since the charging of battery will need the household 240 Volt outlet, the electricity calculations have been carried out for the comparison with petrol expenses.

A rough calculations to compare a gasoline powered car (Toyota Vios) and electric vehicle (Nissan Leaf) have been carried out:

a. EV: RM 0.047 per kilometre

b. Gasoline car: RM 0.14 per kilometre

Also, an EV car does not need maintenance fees as needed by a conventional gasoline-powered car. For instance the frequent oil changes, replacements of filters, and exhaust system repairs. Some components replacement, though less frequent, should be taken into considerations as well. For example the water pump, fuel pump, alternator, etc.

- *More future jobs opportunities*

It can be predicted that there are growing job opportunities in the future. Just imagine that there will be numbers of recharging stations available nationwide, as frequent as petrol stations along a city route.

Also, a lot of skilful technician will be needed for the battery replacement process. Services and maintenance of an EV is definitely different from a conventional gasoline-powered car, hence more efforts should be carried out by related industries to produce more work force on this field.

1.3 Disadvantages of Electric Vehicle

- *Limited mileage*

It is due to the current battery technology limitation. Common electric cars are using lead-acid battery array where it can support a driving range from 70-100km per single charge. An EV that is using Lithium-ion battery array (great example: Tesla Roadster) can travel up to 350km per single charge. Of course, the Li batteries are much more expensive as comparable.

- *Long Recharging period*

It is considered long as compared relatively to the time spent at petrol station. A petrol refilling process might only take up to 3-4 minutes; while a battery recharging will take roughly 4-5 hours on a 240 Volts system.

Example: Lead-acid battery packs with 14700Watts capacity (196 Volts DC, 75AH) will take 4 hours on Malaysia 240 Volts system (240Volt supply with 15A circuit breaker).

- *Limited Recharging Stations*

Recharging stations should be as many as petrol stations are, if electric vehicles are taking over the role of conventional gasoline-powered vehicles. Also, the recharging stations should have developed technology to recharge batteries within a short moment or else it will end up with a super long queue at recharging stations.

1.4 Aims and Objectives

i. Develop a precise system to accurately calculate battery capacity by considering different factors acting on electric vehicle along a journey

ii. Study about motor behaviors and develop a motor speed monitoring system

iii. Develop a data logging system and Graphical User Interface of electric vehicle smart control system

iv. Serve as platform for UTAR continuous development in electric vehicle

1.5 Scope of Project

The scope of this project includes the battery power management, converters and controller, motor characteristics and selection studies, regenerative braking and real time monitoring system. This research project can be divided into three main portions:

Part 1: Gather all required information about the electric car such as:
• Battery type: Lead Acid battery
• Battery voltage: 192V
• Maximum speed: 130km/h
• Maximum Torque: 210Nm
• Range: 300km
• Motor type: DC brushless motor

Part 2: Studies and enhance the currently available battery power management and distribution system which includes the ultrafast charging and discharging system, charging methods, comparison for rechargeable batteries based on the use of Lead Acid battery. The whole system will be monitor through real time operation platform. The study also includes the controller which includes converters (DC-DC), inverters (DC-AC), four quadrant high frequency power electronics switching circuit for maximum power transfer factor from the battery to motor and base drive circuit, phase converter driver circuits and regenerative braking system. The motor controller and base driver circuits is to control speed, direction, torque and regenerative braking system.

Part 3: To assemble and convert a normal IC engine car into an electric car as a primary platform for further testing on the battery energy usage, real time controller, feedback system and on road performance profile. These studies will provide a fundamental platform for further studies on commercially available electric cars in market.

CHAPTER 2

LITERATURE REVIEW

2.1 About Electric Motor

Other than the battery pack, another main feature of an electric vehicle is the electric motor. The electric motor gives the name of “Electric Vehicle”; while battery pack is used to power up the electric motor. Electric motors replace the role of internal combustion engine in conventional gasoline-powered car.

A proper selection of electric motor in an EV is an important issue; these requirements should be considered:

i) High efficiency over wide speed range
ii) High efficiency for regenerative braking
iii) High instant power and high power density
iv) High torque at low speed; high power at high speed
v) Cooling method
vi) Fast torque response
vii) Downsizing and weight reduction
viii) Reasonable costs
ix) High reliability and robustness over various driving conditions

When an electric motor is required to operate over wide speed range, the efficiency issue becomes an important issue. A loss caused by inefficiency can contribute to the calculation failure or calculation inaccuracy. An efficient electric motor means that it could be smaller due to smaller heat disposal would be needed. A lighter weight electric motor is definitely a better choice in an electric vehicle. Downsizing and weight reduction can be achieved by choosing a higher efficiency electric motor; various electric motor requirements are actually inter-related.

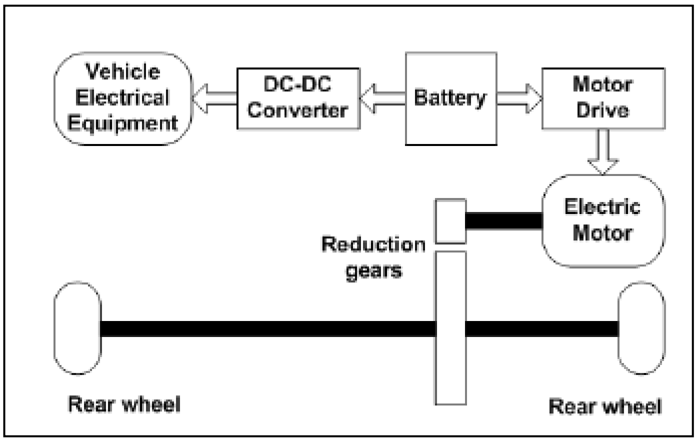

Figure 2.1: Schematic of internal systems of an EV

The difference between cooling methods is always an important factor. A motor with air-cooling method must be large enough to dispose heat generated due to losses. A smaller motor can remove same amount of heat losses if liquid cooling method is used.

As with the case of motor efficiency, the electric motor type chosen is much less important than other factors when it comes to the specific power and power density of an electric motor. The one exception to this is the brushed DC motor because a high proportion of the losses are generated in the rotor.

An electric motor with higher speed leads to a higher power density. The size of electric motor is strongly depending on the motor torque; the motor power does not influence the motor size much as compared with the motor torque. An electric motor with higher torque and lower speed will be larger, for instance those electric motors used in electric forklift.

For electric vehicles, lighter and smaller motors are desired; hence high speed electric motors with gearbox are used. Gearbox is used with a high speed motor whenever a low speed rotation is needed. Gearbox is not necessary used with an electric motor; hence it is possible to use a high speed motor directly coupled to the axle.

Geared motors and gearless motors are different in their configurations; where the geared motors need transmission between the motor and the wheel. Yet, this transmission between motor and wheels means that another consideration should be taken into account, which is the transmission loss. The reason is due to a transmission can never be 100% perfect.

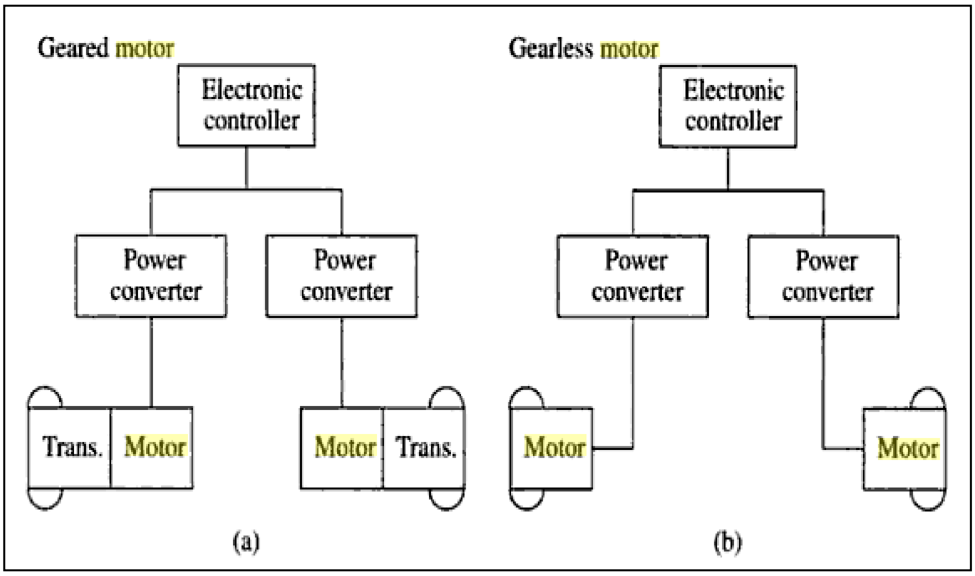

Figure 2.2: Difference between geared motors (transmission involved) and gearless motors (direct coupled)

Selection of electric motors shall consider the system voltage of the particular electric vehicle because different electric vehicles types will adopt different system voltage levels. System voltage level is governed by the battery pack used; while a battery pack weight is nearly 30% of the total curb weight. Hence, choose a higher power motor means that higher voltage levels are needed.

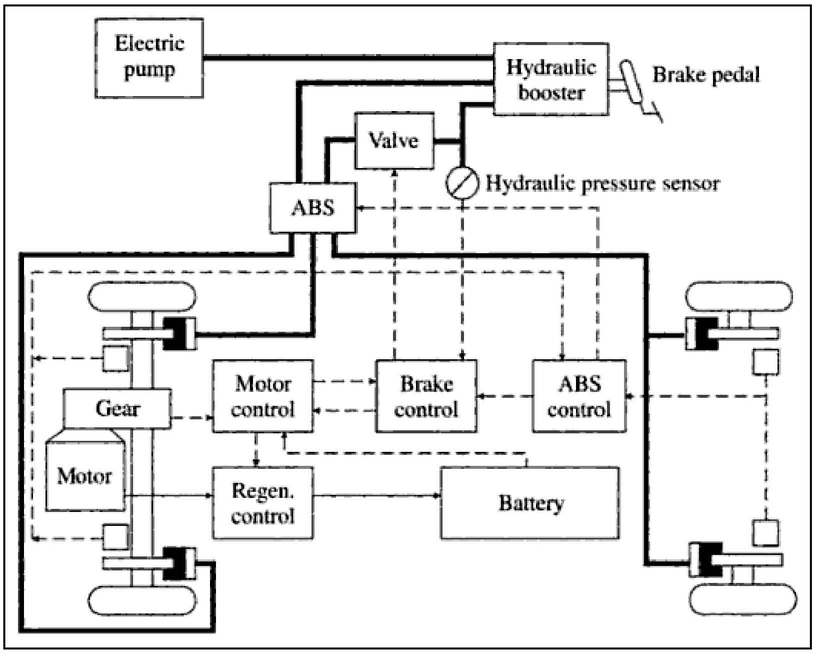

Figure 2.3: A regenerative-braking system configuration

As shown in Figure 2.3, regenerative braking is an important feature when electric vehicle technology is being discussed. Regenerative braking system allows the vehicle's kinetic energy to be converted back to electrical energy during braking.

The regenerative braking system is activated when an electric vehicle is decelerated for speed reduction, the accelerator pedal is released for coasting at highways, or the brake pedal is pressed for stopping the car. Due to the need of converting energy, an electric motor must have high efficiency for regenerative braking.

A fast torque response is needed for electric motors in electric vehicle; high torque is generated when an electric vehicle is climbing uphill, hence a fast response is required. While the reliability and robustness of electric motors under various driving conditions should be kept as high as possible to make the electric vehicle lasts longer.

2.2 Brushless DC Motor

By considering waveform feeding into the motor terminal, permanent magnet (PM) brushless motor drives can be classified as:

i. PM DC motor drives
ii. PM AC (synchronous) motor drives

They are called brushless motor drives because they have no brushes, commutator and slip rings. The reasons for not considering brushed DC motors are shown in the table below:

Table 1: Comparisons between brushed DC motors and brushless motor

Brushed motor	**Brushless motor**
1. Need brush/commutator assembly	Uses electronic controller (precise, efficient)
2. The brushes eventually wear out	No brushes to wear out
3. Sparking and electrical noise by brushes	No sparking and much less electrical noise
4. Harder to cool due to the electromagnet in the centre of motor	Easy to cool with the electromagnets on the stator
5. Uses of brushes limit poles of armature	Can have a lot of electromagnet on stator for precise control

PM synchronous motor drives are fed by sinusoidal or near sinusoidal ac waves and uses continuous rotor position feedback signals to control the commutation. The difference between these two motor drives is that the PM brushless DC motors are fed by rectangular ac waves and uses discrete rotor position feedback signals to control the commutation.

As comparison, PM brushless DC motor is preferred in an electric vehicle. The reason is due to the higher power density than PM synchronous motor drives. The interaction between rectangular field and rectangular current in the motor can produce higher torque product; hence PM brushless DC motors have higher power density.

PM brushless DC motor drive is one of the good choices for electric vehicle because it is most capable to compete with induction motors for electric propulsion among modern motor drives. Advantages of PM brushless DC motor drives include:

i) Due to the magnetic field is excited by high-energy permanent magnets, the overall weight and volume can be reduced for a given output power (high power density)
ii) Higher efficiency than induction motors due to the absence of rotor copper losses
iii) Higher efficiency in dissipating heat to surroundings due to the heat mainly arises in the stator
iv) The rotor acceleration at a given output power can be increased due to the lower electromechanical time constant of the rotor

A DC motor can run in a range from 96V to 192V. It can consist of 8-16 batteries in series (each 12V). DC installation is simpler and less expensive as compared to the AC motor.

A significant advantage of DC motor is that it can overdrive up to a factor of 10-to-1 for a short moment. For instance, a 10kW motor can accept 50kWatt for a short moment and deliver output 5 times higher than its rated horsepower. Hence, it is good for acceleration. This feature can help to deliver a high output torque whenever it is needed, for instance during an uphill condition.

Yet, an extra monitoring should be included due to the heating of motor (caused by overdriving) to avoid the self-destruction of the DC motor.

2.3 GPS modules on Electric Vehicles

Since the early 1970s, the Global Positioning System (GPS) was developed by the U.S. Department of Defence (DoD). GPS is a satellite-based navigation system developed as a military system initially. Since Bill Clinton announced to release the restriction on accuracy of Global Positioning System (GPS) on May 2000, the GPS has become widely used in the positioning system of vehicular technology.

GPS consists of a constellation of 24 operational satellites. To ensure continuous worldwide coverage, GPS satellites are arranged so that four satellites are place in each of six orbital planes. With this constellation geometry, four to ten GPS operational satellites can be visible anywhere globally. Since only four satellites are needed to provide positioning information, an uninterrupted service can be ensured.

GPS provides continuous positioning and timing information to unlimited number of users globally, as long as the users are holding GPS receiver modules.

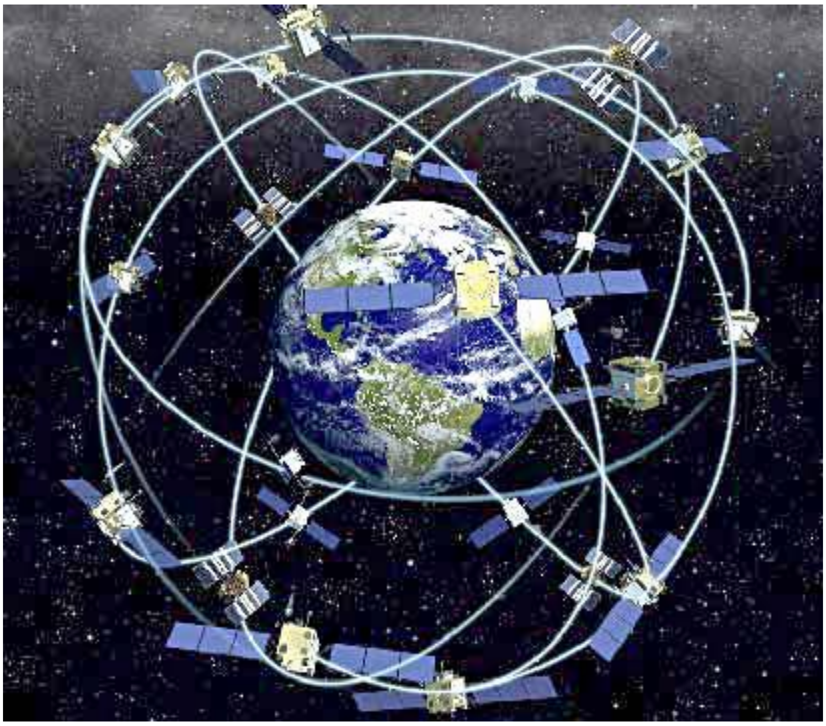

Figure 2.4: GPS satellites constellation

Built-in GPS receivers are usually available in an EV; hence computations can be done to show the vehicle positions in three dimensions and the time. According to the exact vehicle position, the map-matching technology and the current traffic information, the navigation system will recommend the shortest and/or most energy efficient route (minimum traffic jam). Prediction of the residual driving range for EV is done by on-board computer with information obtained from the GPS.

GPS navigation system on electric vehicle consists of the GPS receiver, GPS antenna, navigation computer, display screen (touch screen panels are common) and audio speaker. Once a destination is selected by EV driver, the navigation will start computation for both range and time estimation to provide visual display and audio prompts to assist the driver heading to the desired destination.

GPS navigation systems can be implemented on both internal combustion engine vehicle (ICEV) and electric vehicle; the difference among them is that an extra feature is available on electric vehicle only. Electric vehicles have battery management system (BMS) to coordinate with the navigation system to compute remaining battery capacity after a pre-selected destination. These computations are done based on some assumptions like travelling in city area and travel under constant speed conditions.

Figure 2.5: On-board navigation system in an electric vehicle

2.4 Great Circle Distance

The great circle distance refers to the shortest distance between two points on a sphere surface. There is a unique great circle between two points on a sphere that are not directly opposite to each other. Hence these two points will separate the great circle into two arcs; the length of the shorter arc is the great circle distance between these two points.

Calculations to find out the surface distance between two horizontal positions are performed by assuming spherical Earth; several steps are required by manipulating the latitudes and longitudes.

A calculation method having good accuracy for both long distance and short distance is used to determine the great circle distance, known as the Haversine formula. R refers to the Earth's radius (mean radius = 6,371km).

$$a = \sin^2(\Delta lat/2) + \cos(lat_1) \cdot \cos(lat_2) \cdot \sin^2(\Delta long/2)$$

$$c = 2 \cdot atan2(\sqrt{a} \cdot \sqrt{(1-a)})$$

$$d = R \cdot c$$

2.5 Google Earth for Elevation level

Google Earth is a virtual globe, map and geographical information program gathering global information allowing users to see 3 dimensions buildings, imagery and terrain.

Users are allowed to find cities, places and local businesses by installing Google Earth on their personal computers. Google Earth maps the Earth by the superimposition of images gathered from satellite images, aerial photography and Geographical Information System (GIS) 3D globe.

The Google Earth programs has an extra credit as compared to other websites providing satellite images which is the ability to show sea elevation level for a selected point on Earth surface.

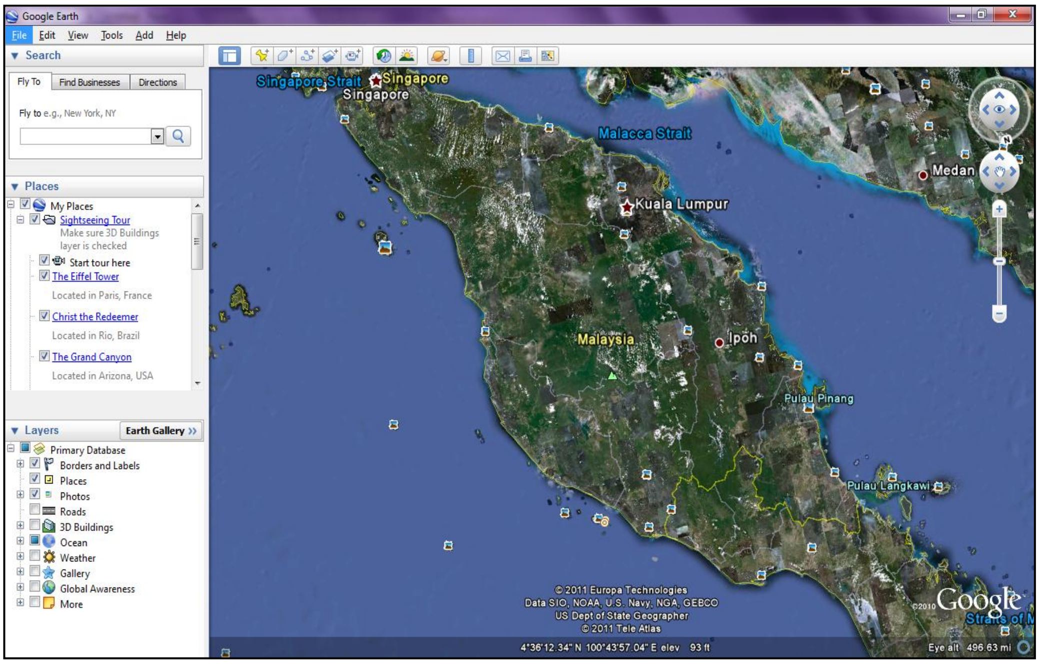

Figure 2.6: Sample interface of Google Earth

The World Geodetic System (WGS) 84 is highly acceptance as a primary reference coordinate system because the Global Positioning System (GPS) derives coordinates from the broadcast ephemeris by referring to World Geodetic System 84. It is geocentric and globally consistent within ±1 m.

This reference system incorporates more data, better computational techniques, a better knowledge of Earth, and improved accuracy as compared to the earlier standards like WGS 66 and WGS 72.

2.6 Battery Management System (BMS)

Electric vehicles need BMS, just like they need battery pack and electric motor. Monitoring the battery pack under various conditions is a crucial task to be done in real-time. Some batteries can be damaged or destroyed if they are over-charged; hence BMS is necessary as a basic requirement in electric vehicles.

BMS can be categorized into the following choices:

i) Small embedded system with simple LED display, low cost and no operating system involved.

ii) Small to medium level computer with real time operating system, lots of input/output (I/O) options, LCD display and storage capability.

iii) Commercial computers with common features of a personal computer

iv) Commercial BMS with high price

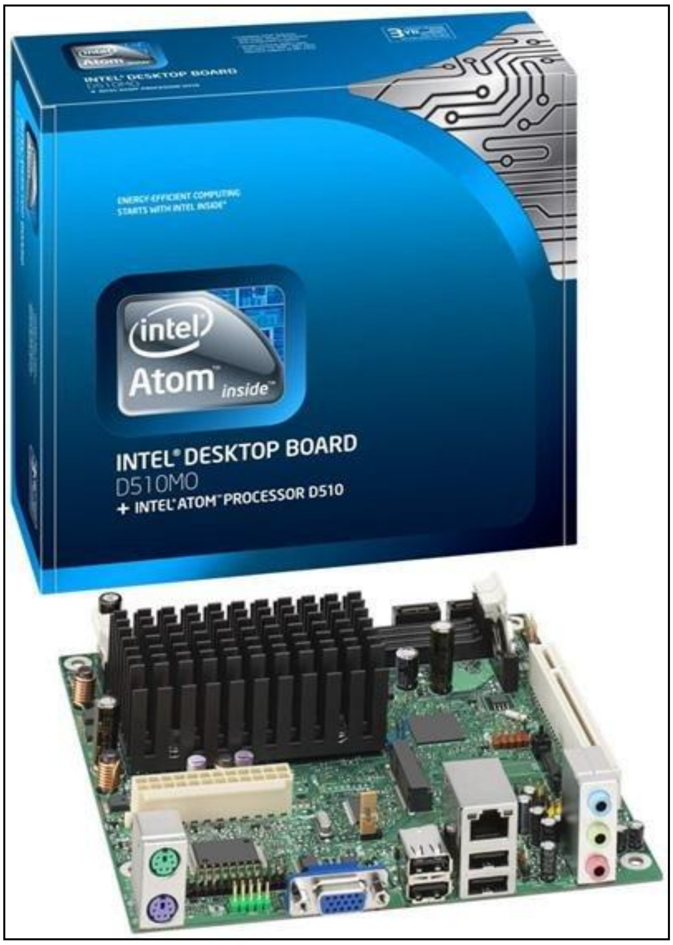

Figure 2.7: Intel desktop board used in EV BMS

CHAPTER 3

CONTOUR POSITIONING SYSTEM (CPS)

3.1 Background

The heart of an electric car is the battery technology which is causing the invisible wars among giant car makers. While enjoying the zero-emission technology from electric cars, the awareness of having sufficient battery capacity for completing a certain journey is important. Electric cars using different battery technology will have different drive distance; different battery charging profiles will also lead to varied charging time needed.

Yet, battery life estimation is an important idea in the electric vehicle development since it will directly determine the car performance. Just imagine that an electric car owner is wishing to reach a destination 50km away from his current location; yet due to his battery life estimation system is not accurate enough and finally end-up with the car stalled half way. It is a condition where all the electric car owners do not wish to face.

Range estimator on an EV dashboard will always get high attention and is one of the main topics people are arguing and complaining about. There are some stories shared by EV drivers about of how their EVs have let them down by predicting longer ranges than they were actually able to drive. All these cases have even lead to a new term among EV drivers, known as “Range Anxiety”. Yet, the approximation of State of Charge (SOC) is still an approximation. What can be done is to cut down the estimation percentage and increase the accuracy of so-called "calculation".

3.2 Introduction to CPS

GPS receiver used in a car can give the approximated distance difference between current location and selected location; a range estimator can calculate the time duration to reach the selected destination.

When the GPS receiver is used in an electric vehicle, it is even more important than it is in a gasoline powered car because an electric vehicle will need to calculate the state of charge (SOC) based on the distance travelled and the time needed to reach a selected destination.

The battery capacity estimation technology in electric vehicle will somehow affected by a selected destination; the variations in road friction, altitude and hill slope conditions will cause the SOC estimation results differ from the actual battery capacity.

CPS calculations will enhance the range estimator and battery capacity calculation because it involves the contour condition during an electric vehicle climbing uphill. By getting information of latitude and longitude of a selected route line, slope angle between two points (with sample distance 9m-12m) is calculated by relating it to the sea elevation level between two points. The slope angle is used to calculate force acting on a car during climbing hill condition. Others forces like rolling resistance force (between tires and road surface) and aerodynamic force are included to increase the precision of calculation.

The net force acting on a car is converted to the torque by knowing the car's tire radius; current drawn from the battery pack can be calculated by knowing the torque needed by the EV during uphill condition.

By performing a series of battery capacity calculation, CPS can give a higher precision and accuracy of remaining battery life for reaching the desired location. An onboard touch-screen panel will be embedded on the electric car dashboard with comfortable graphical user interface showing the car user remaining battery life after reaching the destination.

The ultimate purpose of introducing this system is to boost up the reliability of EV range estimation system in the existing EV intelligent control system. A few more steps/calculations done by the on-board computers can be a new step indicating a new technology.

3.3 Research Methodology

A series of calculation steps has been performed to calculate the current drawn from battery pack of an electric vehicle during uphill condition. An inclined plane experiment has been carried out to collect experimental result. Both results from calculation method and inclined plane experiment are compared to prove the CPS calculation method.

3.3.1 Data Collection and Calculations

A route line with significant change of slope angle along the route is needed as the target of data collection; Genting Highland has been selected as the target destination for this purpose. A total distance of 6.424km along the route line heading to Genting Highland has been selected.

The following website [URL: http://www.flashearth.com/] has been referred to obtain latitudes and longitudes information. This website is able to provide sufficient data with accuracy up to meter range. Sets of data are collected with sample distance of 9m to 12m between two points selected. There are total of 607 points with total distance of 6.426km for the route line selected.

Figure 3.1: The overall view of route line along Genting Highland as shown on the reference website [www.flashearth.com]

A transparent sticker with a red circle is used to ensure constant distance between two points selected along the route line as shown on Figure 3.2.

Figure 3.2: Red circle sticker on laptop screen used to ensure constant distance between two points on the map

Lattitude	Longitude	Distance difference(m)	Elevation difference (m)	Angle(°)	Parallel Force (N)	Rolling Resistance Force(N)	Aerodynamic drag (N)	Net force	Torque (Nm)
3.401702	101.783073								
3.401690	101.783159	9	0.0000	0.0000	0.0000	49.0500	55.3751	104.4251	21.2192
3.401653	101.783237	9	-0.3048	-1.9397	-332.0416	49.0500	55.3751	-227.6165	-46.2517
3.401628	101.783320	9	-0.3048	-1.9397	-332.0416	49.0500	55.3751	-227.6165	-46.2517
3.401617	101.783407	9	0.3048	1.9397	332.0416	49.0500	55.3751	436.4668	88.6900
3.401623	101.783493	9	0.6096	3.8749	662.9450	49.0500	55.3751	767.3701	155.9296
3.401638	101.783578	9	0.0000	0.0000	0.0000	49.0500	55.3751	104.4251	21.2192
3.401663	101.783658	9	-0.3048	-1.9397	-332.0416	49.0500	55.3751	-227.6165	-46.2517
3.401700	101.783734	9	0.6096	3.8749	662.9450	49.0500	55.3751	767.3701	155.9296
3.401744	101.783804	9	0.6096	3.8749	662.9450	49.0500	55.3751	767.3701	155.9296
3.401794	101.783873	9	1.2192	7.7147	1316.8996	49.0500	55.3751	1421.3247	288.8132
3.401848	101.783937	9	1.2192	7.7147	1316.8996	49.0500	55.3751	1421.3247	288.8132
3.401899	101.784000	8	1.2192	8.6652	1477.9789	49.0500	55.3751	1582.4041	321.5445
3.401958	101.784059	9	1.5240	9.6109	1637.8444	49.0500	55.3751	1742.2695	354.0292
3.402014	101.784117	8	1.5240	10.7856	1835.7912	49.0500	55.3751	1940.2163	394.2520
3.402072	101.784175	9	1.5240	9.6109	1637.8444	49.0500	55.3751	1742.2695	354.0292
3.402130	101.784234	9	1.5240	9.6109	1637.8444	49.0500	55.3751	1742.2695	354.0292
3.402191	101.784295	9	1.8288	11.4861	1953.4703	49.0500	55.3751	2057.8954	418.1644
3.402250	101.784350	8	1.8288	12.8766	2186.1710	49.0500	55.3751	2290.5961	465.4491
3.402350	101.784412	13	3.0480	13.1953	2239.3404	49.0500	55.3751	2343.7655	476.2531
3.402363	101.784471	6	-0.3048	-2.9081	-497.7062	49.0500	55.3751	-393.2811	-79.9147
3.402420	101.784529	9	1.2192	7.7147	1316.8996	49.0500	55.3751	1421.3247	288.8132

Figure 3.3: Sets of latitude and longitude collected

The selected route line which have different angle of uphill slopes is the uphill route to Genting Highland. Using the sets of data collected as shown in Figure 3.3, Haversine Formula is used to calculate the distance between two coordinates with R_{earth} = earth's radius (mean radius = 6,371km).

$$a = \sin^2(\Delta lat/2) + \cos(lat_1) \cdot \cos(lat_2) \cdot \sin^2(\Delta long/2) \quad (1)$$

$$c = 2 \cdot atan2(\sqrt{a} \cdot \sqrt{(1-a)}) \quad (2)$$

$$d = R \cdot c \quad (3)$$

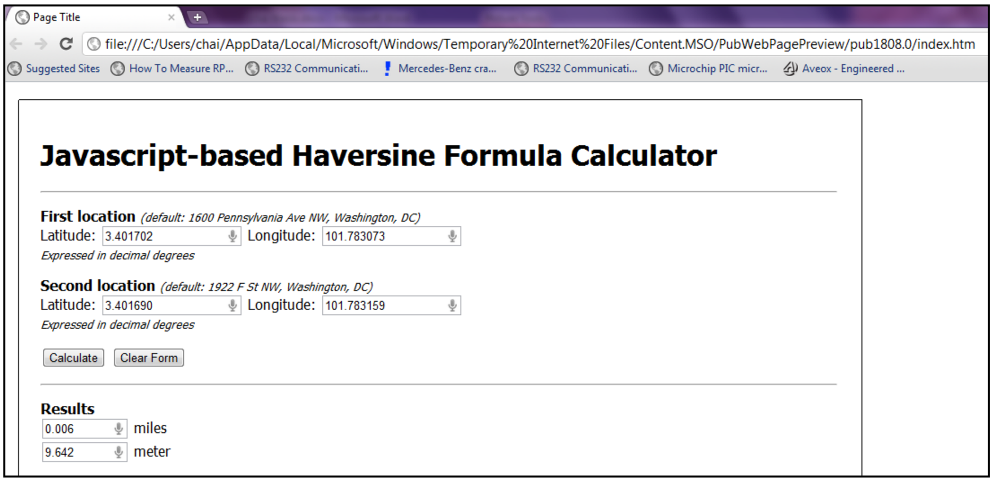

Figure 3.4: Javascript based coordinate distance calculator

For the sake of time-saving, a coordinate-calculator built using JavaScript is used to obtain the calculated distance. As shown in Figure 3.4, the JavaScript based coordinate calculator was built based on Haversine Formula. Programming languages like HTML code and JavaScript are combined to build this coordinate calculator.

Hence, for a set of latitudes and longitudes selected, the distance calculator can be used to show the exact distance between them.

The next step is to make use Google Earth which provides a platform to view the location and the elevation level of that particular coordination. The elevation difference between two points is calculated and it is repeated for the whole route map selected.

With a set of distance differences and elevation differences, the angle (θ) between two coordinates can be calculated by using the following formula:

$$\theta = Tan^{-1}\,(Rise\,/\,Run) \tag{4}$$

First, by ignoring the friction force, the hill climbing force ($F_{||}$) pulling down a car along the inclined plane can be figured out.

$$F_{||} = mg\cdot \sin(\theta) \tag{5}$$

By using gravity constant g= 9.81 m/s^2 and assuming the selected car has a curb weight 1000kg, eq.(5) can be written as:

$$F_{||} = 9810\cdot \sin(\theta) \tag{6}$$

The next scenario is to look into the rolling resistance force calculation.

$$F_{rr} = \mu_{rr}.mg \tag{7}$$

By assuming good tires are used with rolling resistance coefficient μ_{rr} = 0.005, the rolling resistance force can be calculated by using the selected curb weight of 1000kg.

$$F_{rr} = 0.005(9810) \tag{8}$$

The aerodynamic drag (F_D) is the force due to the friction of vehicle body moving through the air.

$$F_D = 0.5\,\rho \cdot v^2 \cdot C_d \cdot A \tag{9}$$

Some assumptions need to be made for the calculations of aerodynamics force:

i) Drag coefficient (C_d) is assumed to be 0.29

ii) Frontal area (A) is assumed to be $2.27m^2$.

iii) Travelling velocity up a hill is assumed to be constantly 50km/h (no accelerating force is involved).

The air density (ρ) can be calculated by first figuring out the temperature (T) and pressure (p) at certain altitude above sea level (h).

Some constants value used in the calculation for aerodynamic drag (F_D):

i) The sea level standard temperature T_0 is 288.15

ii) The temperature lapse rate L = 0.0065 K/m.

iii) The sea level standard atmospheric pressure p_0 = 101325 Pa.

iv) Molar mass of dry air M is 0.0289644 kg/mol.

v) Universal gas constant R is 8.31447 J/(mol·K).

vi) Gravity constant (g) is 9.81 m/s^2.

The following formulas are used to calculate the air density (ρ):

$$T = T_0 - (L \cdot h) \tag{10}$$

$$p = p_0 \cdot \left(1 - \frac{L \cdot h}{T0}\right)^{\frac{g \cdot M}{R \cdot L}} \tag{11}$$

$$\rho = \frac{p \cdot M}{R \cdot T} \tag{12}$$

The particular aerodynamic drag (F_D) acting on the electric vehicle along the uphill journey (Genting Highland) can be calculated using air density at a certain latitude above sea level using (12).

By combining the hill climbing force, rolling resistance force and aerodynamic force, the net force (F_{net}) required for the car to climb uphill can be determined.

$$F_{net} = F_{||} + F_{rr} + F_D \tag{13}$$

The force can be related with torque (τ) by the following formula:

$$\tau = F_{net} \cdot (R_{wheel}/G) \tag{14}$$

Gear ratio (G) of the car shall be determined for the calculation of torque. The selected wheel size (R_{wheel}) determines the finally available torque. By knowing the wheel radius, torque can be calculated as by applying (14).

The data for a distance over 6.4km along the route line towards Genting Highland has been collected and the current needed by the extra torque can be calculated by knowing torque constant (k_t) for the particular electric motor.

$$\tau = k_t \cdot I \tag{15}$$

The calculation can be used on any electric vehicle in order those needed parameters for force calculation are known. The torque calculated through this method is the extra torque needed to climb up this particular route line. Hence current consumption can be linked for enhancement in the battery capacity estimation module in electric vehicle. The table showing steps for calculating extra current drawn from the latitude and longitude data are attached as Appendix.

3.3.2 Inclined Plane Experiment

As shown in Figure 3.5, an incline plane with variable angle is built as the track of a RC model car to simulate the scenario of an electric vehicle driving uphill with certain slope angle.

The inclined plane was built from scrap items like table surface, wood sticks, and iron sticks. Recycled items are used for environmental saving purpose and cost saving purpose.

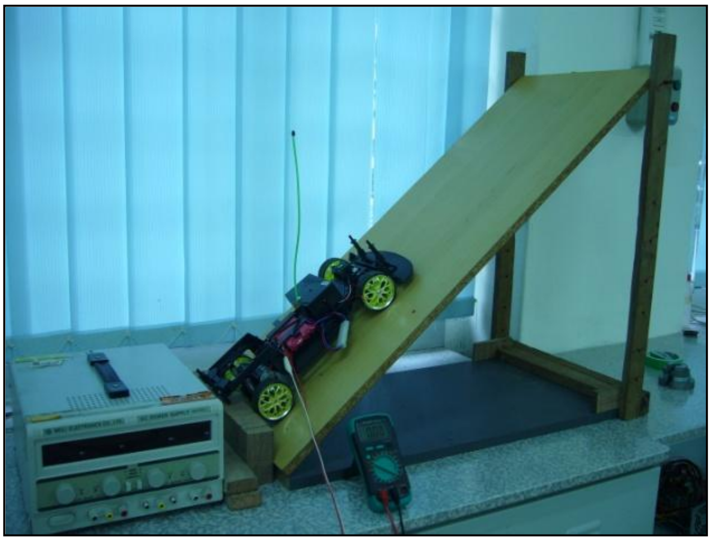

Figure 3.5: Inclined plane built for experimental use

The inclined plane was built to have variable angle selections. It was done by drilling holes at pre-calculated heights to have angle with steps of 5°. Two iron sticks are used to select the desired slope angle.

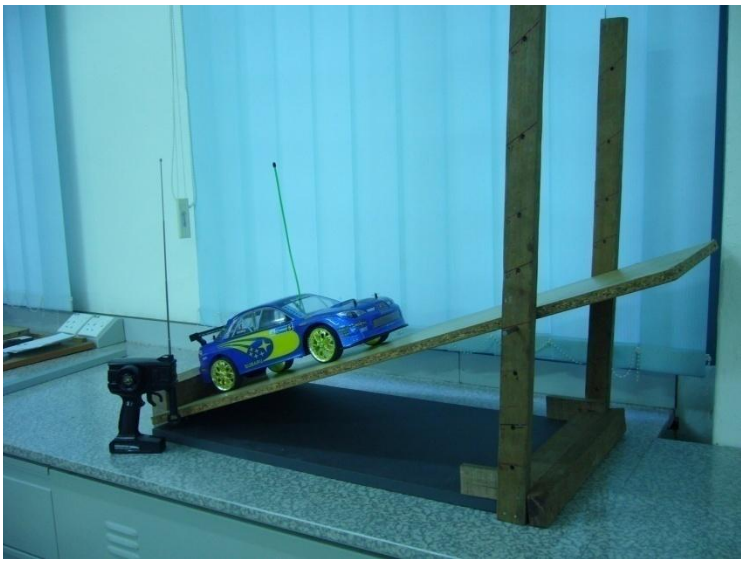

Figure 3.6: Inclined plane experiment with a RC car running on 20° slope angle

A radio controlled (RC) car with 9.6V supply voltage is used to climb up slope with angle from 5° to 40° as shown in Figure 3.6.

The RC car weight is 0.825167kg. Motor in the RC car is the small scale DC motor with 9.6V supply voltage requirement. The battery pack used is the Ni-CD cell with 2800mAh capacity. The inclined plane is built from normal wooden table and the table surface does not provide good friction (plywood). The inclined plane surface is then further tested by adding sand paper to increase the friction coefficient. The sand papers tend to function like asphalt road's friction force onto the car wheels.

There are several methods to express slope or grading systems around the world, mainly is by degree, which is the angle of the slope; and percentage, which is "grade" of the slope degree. The percentage of the grade is calculated by the formula $100\frac{rise}{run}$, where *rise* is the elevation difference or the vertical difference of the two points of interest and *run* is the horizontal length difference of the points.

The torque constant is not given by the motor manufacturer, hence the supply voltage (V_{supply}) motor's maximum no-load RPM ($RPM_{no\text{-}load(max)}$), terminal resistance ($R_m$) and no-load current ($I_{no\text{-}load}$) are measured to calculate the torque constant. The following are the measurements taken:

i) $I_{no\text{-}load} = 0.79A$
ii) $RPM_{no\text{-}load(max)} = 16.652k$
iii) $R_m = 8.48/0.79 = 10.73\Omega$
iv) $V_{supply} = 10V$

The above readings were taken to calculate torque constant (k_t) for the particular RC car used in the inclined plane simulation experiment.

$$k_t=k_b \cdot 1.345 \quad (13)$$

$$I_{motor} = [V_{supply}-(k_b \cdot kRPM)]/R_m \quad (14)$$

Equation (14) can be rearranged as follow:

$$k_b = [V_{supply}- (I_{motor} \cdot R_m)]/ kRPM \quad (15)$$

Where k_b is the voltage constant in unit of $V{\cdot}kRPM^{-1}$, V_{supply} is the voltage supplied to the motor and R_m is the resistance across the motor terminal.

By applying (15),
$k_b = 0.09$.

Then by applying (13), torque constant for the particular DC motor is found.
$k_t = 0.12$ Nm/A.

The torque constant is calculated and it can be used to calculate the current needed to climb up a hill with certain slope angle. The calculated value will then compared with the measured value in the inclined plane experiment.

3.4 Results and Discussion

Table 2: Experimental value

Plane Angle(°)	**Holding Current (A)**
5	1.740
10	2.650
15	3.480
20	4.240
25	5.010
30	5.820
35	6.590
40	7.240

Based on the RC model car with inclined plane experiment, measured values indicating the relationship between current and slope angle are shown in Table 2. The graph plotted based on these results is shown in Figure 3.7 (a full size graph will be attached in Appendix section). Graph plotted gives an equation for the particular RC model car:

$$I = 0.15711905\theta + 1.0610714 \quad (16)$$

This equation gives the relationship between current and slope angle for the particular RC car; each electric vehicle is expected to have a unique equation for this relationship.

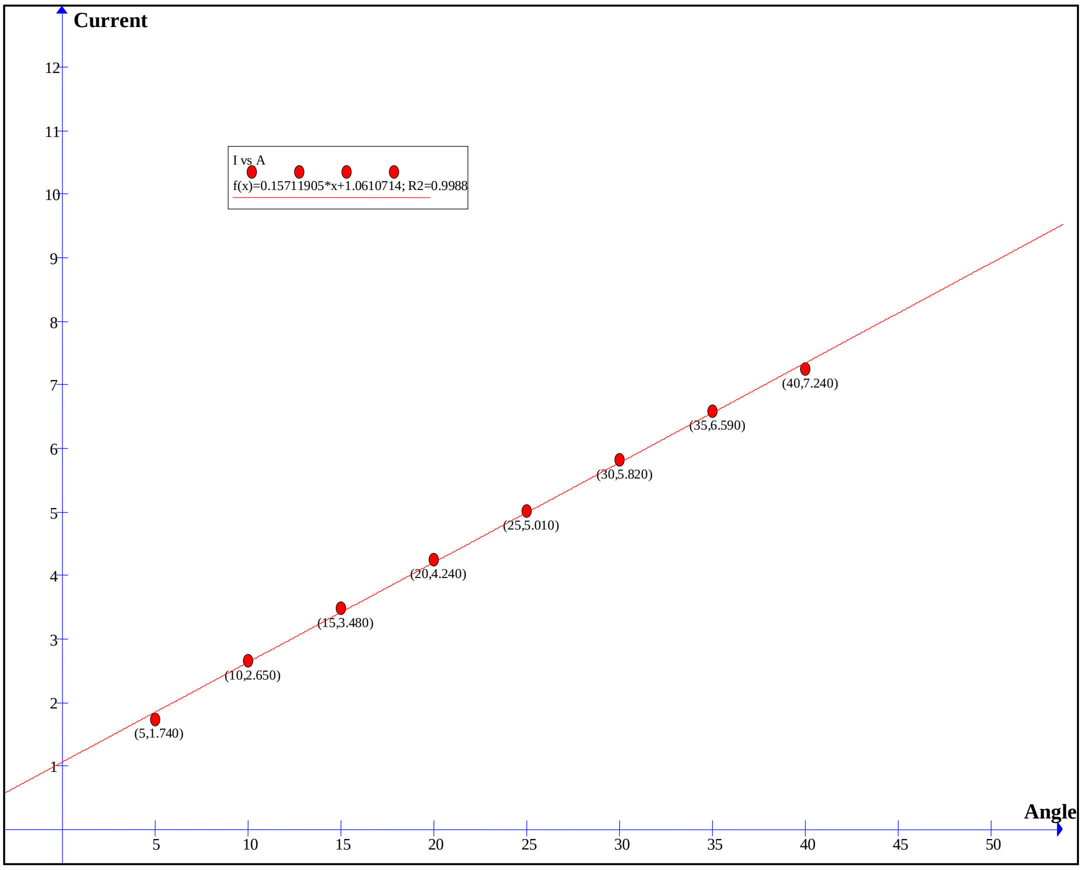

Figure 3.7: Current versus Slope Angle graph based on experimental results

Table 3: Calculated results based on CPS calculation method

Angle(°)	F|| (N)	Frr(N)	FD (N)	Net force	Torque (Nm)	Current (A)
5	0.7055	0.4047	0.0035	1.1137	0.1676	1.396797883
10	1.4057	0.4047	0.0035	1.8139	0.2730	2.274898407
15	2.0951	0.4047	0.0035	2.5033	0.3767	3.139581929
20	2.7686	0.4047	0.0035	3.1768	0.4781	3.984267687
25	3.4210	0.4047	0.0035	3.8293	0.5763	4.802527111
30	4.0474	0.4047	0.0035	4.4557	0.6706	5.588132753
35	4.6430	0.4047	0.0035	5.0512	0.7602	6.33510568
40	5.2033	0.4047	0.0035	5.6115	0.8445	7.037760977

Value 1: Calculated current

Theoretical values of current needed under different slope angle are calculated by applying equations (5) – (15).

Slope condition with angle 15° is used for the comparison.

I_{calc} = 3.14A

Value 2: Experimental value

Experimental results are obtained by measuring current across the RC car motor terminals. Under inclined plane experiment, recorded holding current ($I_{measure}$) on 15° slope angle is 3.48A (refer to Table 2).

Error percentage between calculated current value and experimental current value is calculated:

$$\%Error = \frac{Imeasure - Icalc}{Imeasure} = 9.77\% \quad (16)$$

The difference between theoretical value and measured value is caused by those assumptions made in the calculations using RC car parameters. Elements like drag coefficient of the particular RC car, exact speed travelling uphill, tires' rolling resistance coefficient shall be known in order to give more accurate calculations.

3.5 Suggestions for Improvements

Calculation on the net force applied on the car climbing uphill should consider the frictional force more precisely by applying exact friction coefficient on the particular route line selected.

Another aspect should be considered by taking account the effect of air resistance (drag force, F_D) on the car. Every car has different cross-sectional area (A) and drag coefficient (C_d) and these values are constant values for the particular car. Hence for the calculation of air resistance, values of square of velocity (v) and air density (ρ) shall be determined precisely. The problem when it comes to real-time calculations arises where a selected journey involves a trip from suburban area to a highland area.

The air density will change along the journey and hence a way to choose air density value shall be pre-determined during the system design stage.
To further calculate other forces acting on the electric vehicle during uphill condition, the acceleration force is another element to be analyzed. Yet, it shall be considered under the condition where the car is not travelling at constant speed. Due to the CPS calculation assumes that the car is travelling at constant speed, this acceleration force is not considered.

The comparison between measured value and calculated value shows that there is an error percentage of 9.77%. Since there are actually more forces acting on a car during uphill condition; hence the current calculated is slightly lesser than measured current value. The necessity to involve acceleration force in the calculation shall be considered to improve the accuracy.

Efficiency loss shall be considered because the gear system will never be 100% efficient. A small efficiency loss can cause another variation factor in the real-car calculation and implementation.

When it comes to real world implementation, a lab test is needed to obtain the angle-current profile. A particular electric vehicle should have its own relationship between slope angle and current needed during uphill condition due to different parameters. Average data by repeating the tests shall be obtained to compensate for the efficiency loss that is unpredictable in the calculation method.

CHAPTER 4

MOTOR SPEED MONITORING

4.1 Introduction

Typical motor speed control or monitoring systems need sensors to provide feedback information of the motor. Some common used sensors are listed below:

i) Shunt resistors
ii) Current-sensing transformer
iii) Hall effect current sensors
iv) Hall effect tachometer

Other than these feedback systems, the back electromotive force (EMF) control method can be used to eliminate the requirement for relatively expensive sensors, such as Hall Effect devices. Back-EMF control method has its advantage over other motor speed monitoring method due to the sensorless configurations. This control method obtains the speed and position of the motor directly from the voltage at the motor windings.

This method can be used in brushless DC motors to provide monitoring of the motor speed. The back EMF is created when the motor's armature turns, which creates an electrical kickback or EMF that can be sensed as a voltage through a resistor.

The amplitude of the EMF signal increases with the speed of the armature rotation. Amplitude of back-EMF voltage is directly proportional to the motor speed. A drawback of this method is that the amplitude of the signal is very small at low shaft RPMs.

4.2 Research Methodology

The back-EMF motor speed monitoring system needs a DC motor and a core microcontroller to read the feedback voltage from the motor terminal as well as doing analogue-to-digital conversion.

4.2.1 Microcontroller with multiple I/O options

Choosing the correct microcontroller is an important step because features available in the particular microcontroller will decide amount of tasks that can be done. After comparing various types of microcontroller, PIC24 with a Dual Inline Package (DIP) design has been chosen. PIC24 is preferred than those 8-bits microcontroller (MCU); it is a 16-bits MCU featuring a set of 16 working registers.

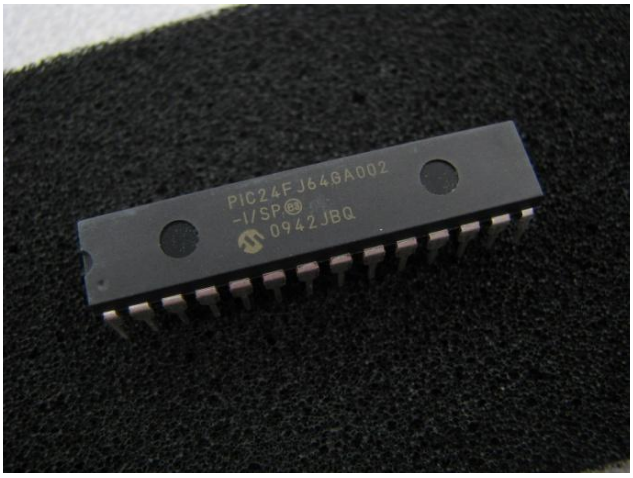

Figure 4.1: PIC24FJ64GA002

As shown in Figure 4.1, PIC24FJ64GA002 has been selected for the motor speed monitoring purpose.

Some important features of the selected microcontroller are shown below:

i) 8MHz Internal Oscillator
ii) Operating Voltage range from 2.0V to 3.6V
iii) Low Operating Current at 650µA
iv) 64Kbytes Program Memory
v) 10-bits Analog-to-Digital Converter (ADC); up to 13 channel
vi) 16 Remappable Pins
vii) Support Universal Asynchronous Receiver/Transmitter (UART)

The 10-bits ADC feature of the PIC24 makes it possible to take the back-EMF voltage generated by motor terminals of DC motor as input voltage for conversion process. The drawback of this PIC24 is that it can only accept an input voltage for not greater than 3.6V for an analogue pin; while the maximum back-EMF generated during the maximum motor speed is higher than 9V.

To overcome this, a simple voltage divider circuit has been constructed to scale down the voltage (3.3V). Small value resistors are used in the voltage divider circuit because the PIC24 cannot detect the input voltage if the input current is too low. 27Ω resistors are used to ensure the current flow through is kept above 100mA.

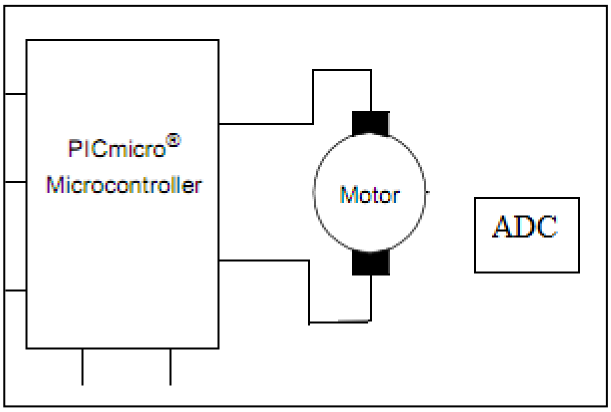

Figure 4.2: Schematic between microcontroller and DC motor

In order to program the PIC24, a PICkit2 was built to provide Universal Serial Bus (USB) connection to a computer.

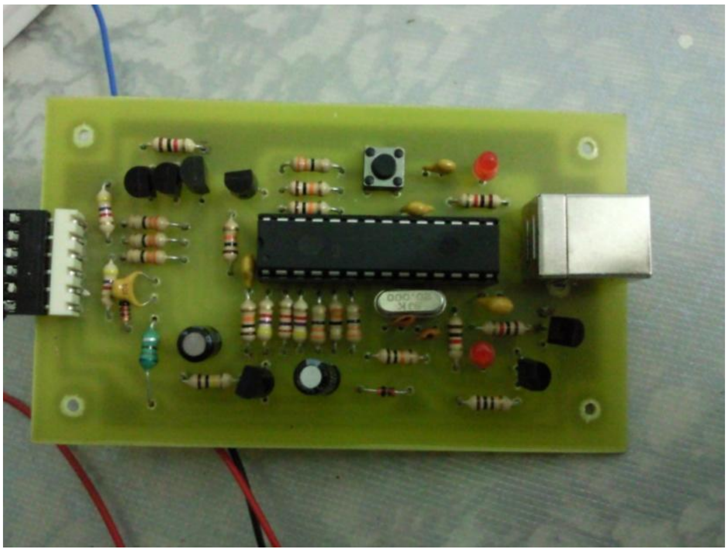

Figure 4.3: Self-built PICKit2 programmer

The compiler used to program the PIC24 using self-built programmer is the MPLAB Integrated Development Environment (IDE) by Microchip. Easy-to-learn interface is provided with powerful debugging tools and simulators. The MPLAB IDE supports programming with C languange and it can be used to program various types of microcontroller.

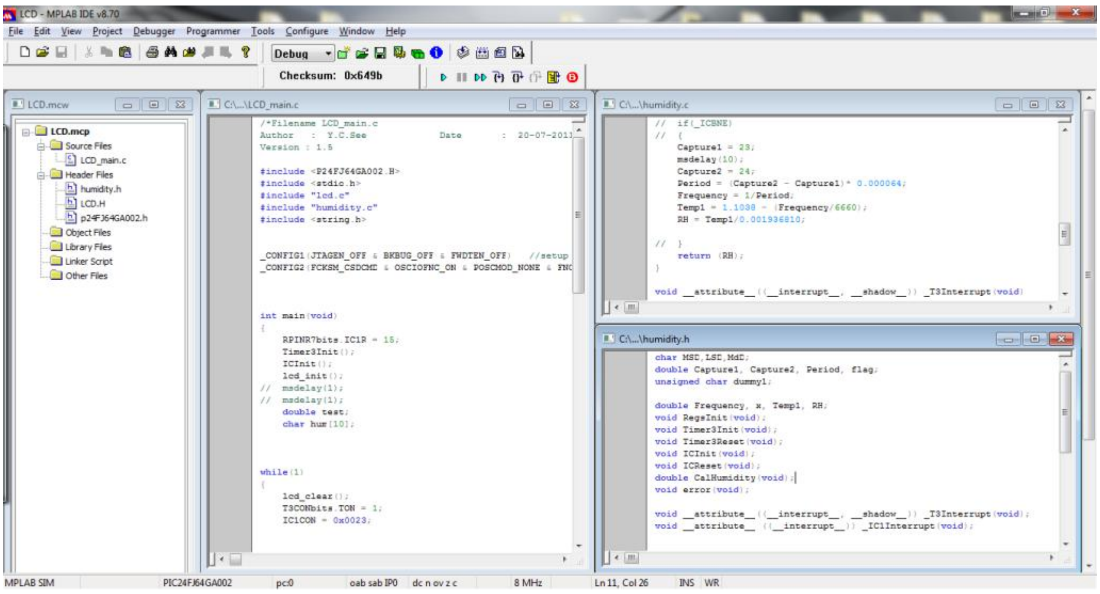

Figure 4.4: MPLAB IDE user interface

Once programming code has been done debugging under MPLAB IDE, the exported hex code can be programmed into the target board (PIC24) using PICkit2 v2.61 as shown in Figure 4.5.

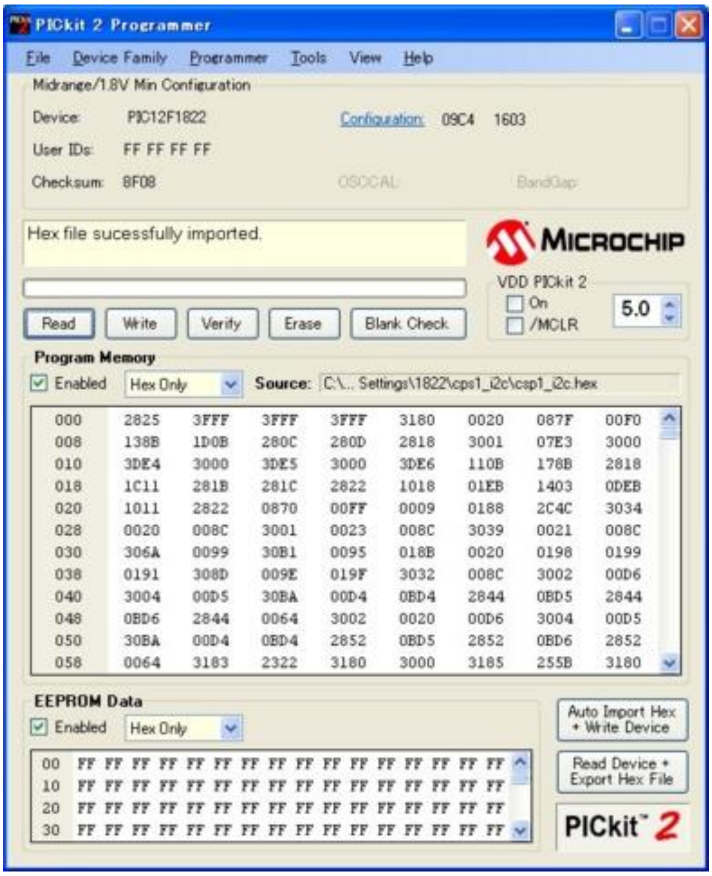

Figure 4.5: PICkit2 v2.61 programmer interface

4.2.2 ADC Conversion and LCD display

Programming stage:

i) Set one pin as analogue input pin (RB0) to read back-EMF voltage

ii) Set one pin as input pin (RB1) to be connected with a switch

iii) Set 6 pins for output pins (RA0-RA5) to be connected with a LCD display

iv) Initialize ADC conversion

v) Initialize LCD

vi) Read from ADC conversion and send string to LCD

A LCD display with 16x2 characters dot matrix display has been selected; the model is JHD162A as shown in Figure 4.6.

Figure 4.6: JHD162A LCD display

One of the motor terminals is connected to RB0 pin of PIC24 as the back-EMF voltage and another terminal is connected to the common Ground of PIC24. Long jumper wires are used to connect both the motor terminals to ensure continuous data reading during the RC car running condition.

Maximum motor speed during no load condition was measured using tachometer and the corresponding back-EMF voltage generated was recorded. By knowing the maximum back-EMF voltage, the voltage divider circuit was constructed to scale down the voltage level for not exceeding 3.6V. This was done to protect the input/output (I/O) pins of the PIC24.

The 16x2 characters dot matrix LCD display and the internal ADC of PIC24 need to be initialized before they are used; hence initialization coding have been written and imported as library in the main program.

4.3 Results and Discussion

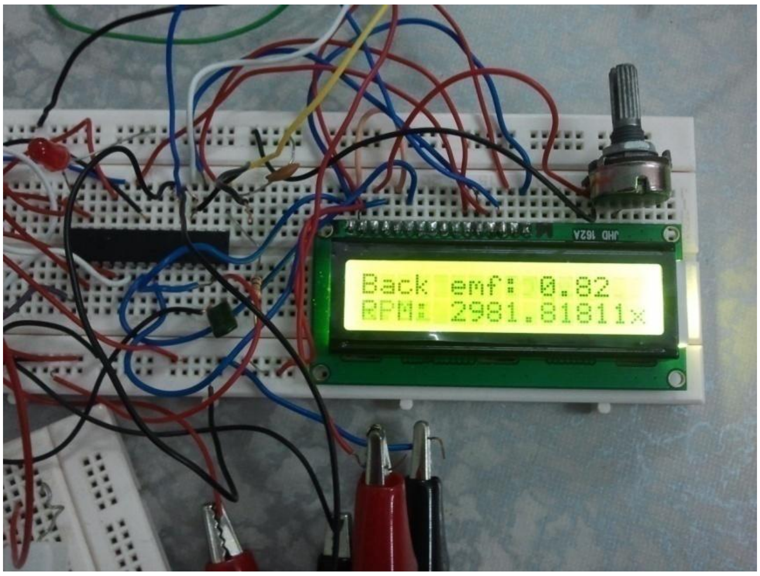

Figure 4.7: LCD display showing updated back-EMF voltage reading and calculated rounds-per-minute (RPM)

After the ADC conversion interrupt occurs, the PIC24 will calculate the corresponding Rounds-Per-Minute (RPM) with ratio to the back-EMF voltage level.

The conversion was done according to the 10-bits internal ADC of PIC24, with accuracy up to 0.1% and resolution of 3.2mV. Due to 16 buffer calculations are selected instead of 1 buffer, the average value converted is more accurate.

4.3.1 Problems encountered

The problem encountered in this method was the voltage drop after the back EMF voltage being feed to the PIC24 as input voltage. For instance, a reading of 2.8V back-EMF voltage will be detected as 2.0V after it is connected to the input pin of PIC24.

The reason was found and it was due to the impedance mismatch. To compensate for this error, several readings were taken and the average value was found to be 0.82V voltage drop.

An extra step of calculation was added in the main program to compensate for this loss of voltage level. Due to this voltage drop, the PIC24 cannot detect the RPM precisely at low motor speed due to the small back-EMF voltage generated by the motor terminals.

4.4 Suggestions for Improvements

This method can give feedback of motor speed monitoring without sensor configurations; yet it is not 100% accurate due to the voltage generated is not stable under low speed condition.

The impedance mismatch case in the methodology also shows that the use of voltage divider configuration circuit is not suitable. Voltage regulator circuit shall be built with desired regulator IC. The selected regulator IC can be chosen with desired electrical characteristics.

Also, the RPM calculated in this method can only give the motor shaft's speed. In order to have the speedometer feature, sensors are still needed to show the vehicle speed in unit of km/hour. For instance, sensors shall be installed at vehicle wheels to measure time between each wheel revolution. Accurate wheel radius shall be known to give precise calculations of vehicle speed.

Lastly, a 32-bits microcontroller can be chosen in order to have a faster response time. More features and output pins can be manipulated for necessary options and operations.

CHAPTER 5

DATA LOGGING AND GRAPHICAL USER INTERFACE

5.1 Introduction

Typical EV intelligent control systems have data logging features to save data to the on-board computers. These saved data can be manipulated by technician or engineers during servicing process; some advanced systems could even access to the database by the control centrals.

Graphical user interface (GUI) to assist EV driver access to the embedded system shall be kept clear and user friendly. Features like temperature monitoring, motor speed monitoring, GPS navigation system and BMS are necessary in an EV intelligent control system. Some extra features like phone calling, e-book reader and infotainment can be added to the secondary screen. These features are going to be implemented in this project; done separately by different members of this project.

5.2 Research Methodology

The data logging features are done using two ways; one is using Electrically Erasable Programmable Read-Only Memory (EEPROM) and another is done using computer solid state hard disk storage. The GUI is designed using Adobe Flash CS3.

5.2.1 Data Logging

EEPROM storage

The first option was to store date read from sensors to EEPROM through I2C 2-wire protocol. An EEPROM with model NM24C04 is connected to the PIC24. The EEPROM uses two I/O pins of PIC24; hence it can store 4K bits with minimized pin counts. It is used to serve as backup memory storage if the serial connection to the computer fails.

Computer solid state hard disk storage

In order to save feedback data from sensors installed on electric vehicles, data must be passed to computer through the microcontroller. Serial connections are needed between the computer serial ports and the microcontroller. An Intel Desktop Board D510MO has been used as the on-board computer; two serial ports are available for serial communications.

5.2.2 Recommended Standard 232 (RS-232)

RS-232 is a standard developed by Electronic Industry Association (EIA) and it is one of the most widely used communication interfaces. RS-232 is used to connect a Data Terminal Equipment (DTE) to a Data Circuit Terminating Equipment (DCE).

RS-232 refers to serial communication; hence bits are transmitted serially. Communication between two devices connected using RS-232 is full duplex; which means that the data transfer can take place in both direction. In this project, data are transferred from the microcontroller to the computer.

In order to transmit data through RS-232 from a microcontroller, an extra circuit is needed. The particular circuit is known as MAX232 serial level converter. MAX232 is an integrated circuit used to convert signals from RS-232 serial port.

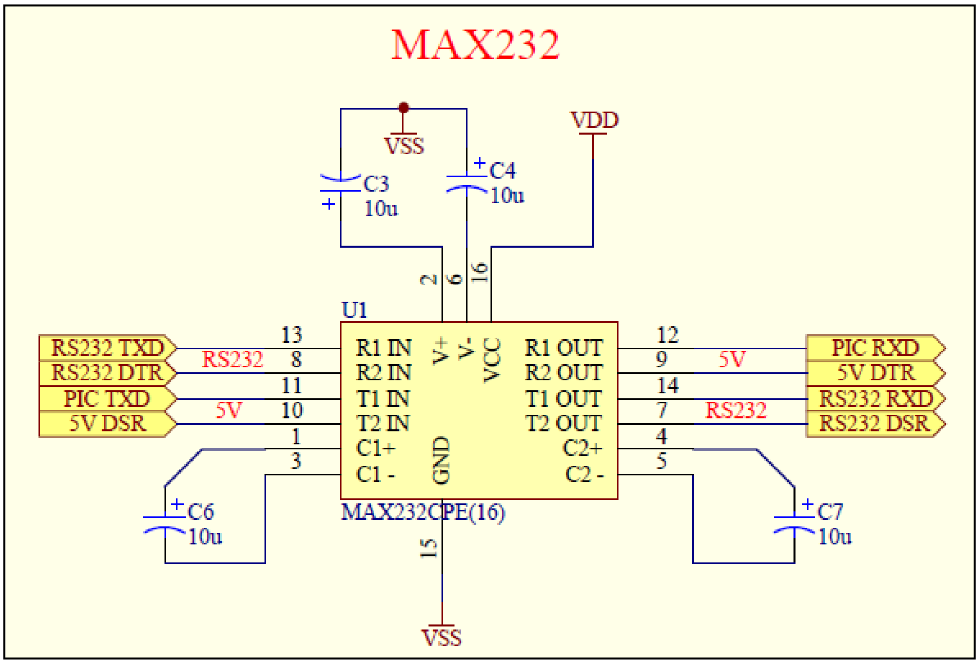

Figure 5.1: MAX232 schematic diagram

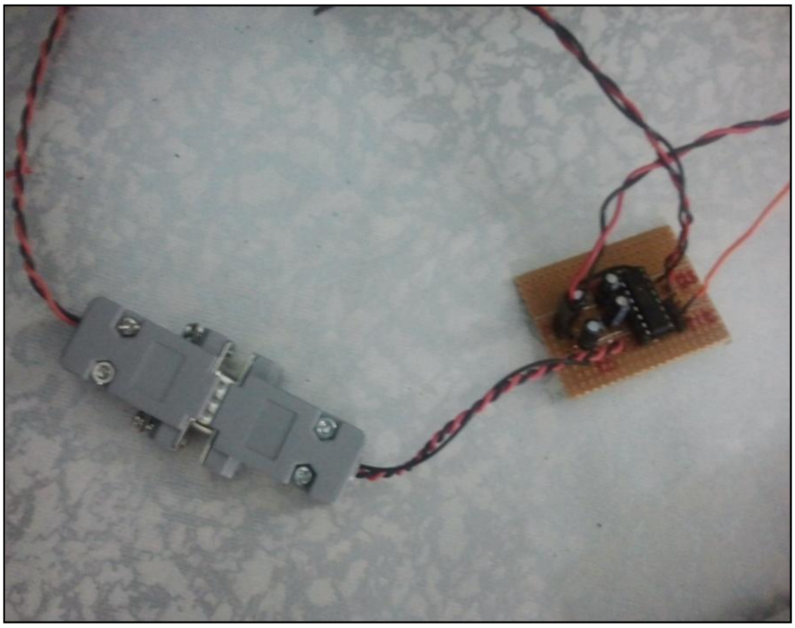

Figure 5.2: MAX232 circuit with RS-232 cable

By having this serial level converter circuit, data processed by internal ADC of PIC24 can be transmitted serially to the computer. Data received through the computer serial ports can be accessed through some terminal program such as HyperTerminal, SerialTerm and PuTTY.

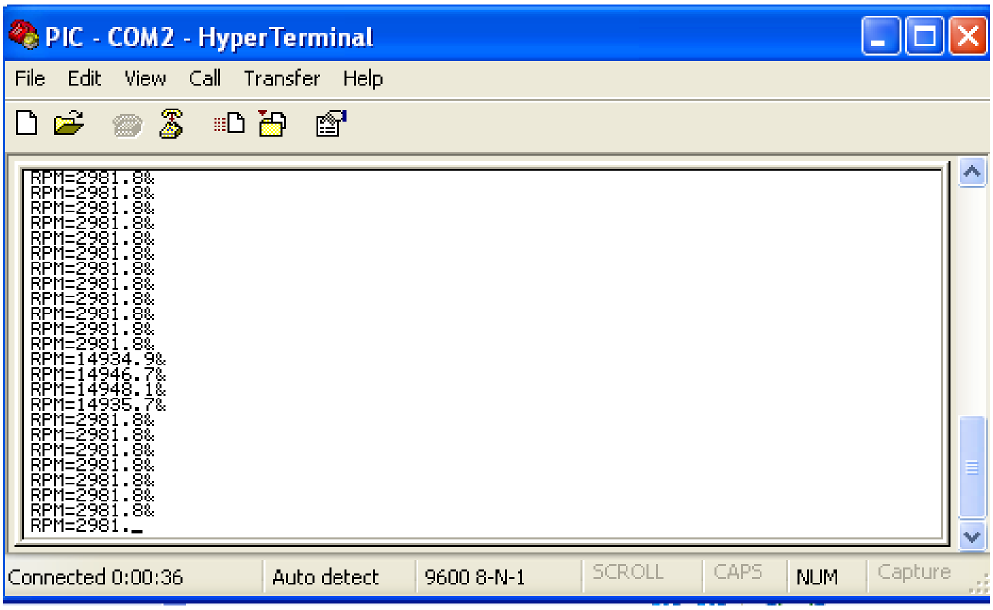

Figure 5.3: Motor speed monitoring through HyperTerminal

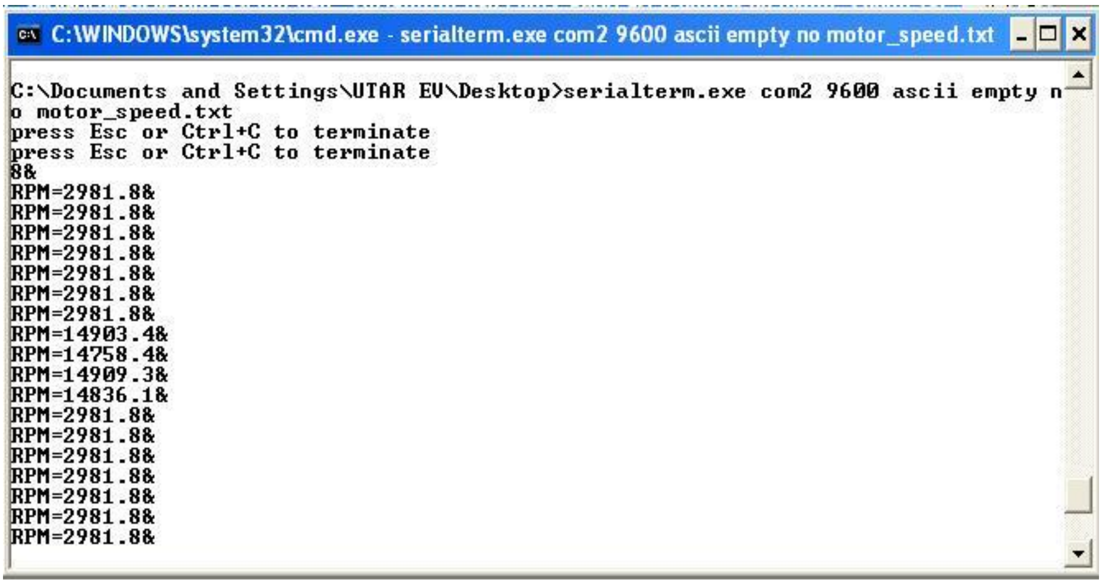

Figure 5.4: Motor speed monitoring through SerialTerm

Figure 5.5: Motor speed monitoring through PuTTY

Data received through serial ports can be stored in text file format and it can be saved to specific folders according to the user setting. The text file is set to be saved in a format such that there is no space between incoming data. This text file can be manipulated later as input for graph plotting or input for Flash design.

5.2.3 LoadVars Method in Adobe Flash

GUI design was done using Adobe Flash CS3. The output file format is a Shock Wave Flash (SWF) file. A SWF file is a window for capturing and displaying information. Adobe Flash does not have communication ports; hence it cannot communicate with serial ports directly.

Using ActionScript functions and methods, information can be sent and received from text files and XML files. In addition, server-side scripts can request specific information from a database and relay it to a SWF file. Server-side scripts can be written in different languages: some of the most common are CFML, Perl, ASP (Microsoft Active Server Pages), and PHP.

By storing information in a database and retrieving it, dynamic and personalized content for the SWF file can be created. For example, motor speed monitoring can be done by continuously reading data from the text file “motorspeed.txt”. The text file should be stored in the same directory as the SWF file; hence the setting in the RS-232 terminal program should be configured to match this requirement.

LoadVars method is used to access data from a text file; the source code is written as below:

```
var myTextLoader:URLLoader = new URLLoader();
myTextLoader.addEventListener(Event.COMPLETE, onLoaded);

function onLoaded(e:Event):void {
 var speed:Array = e.target.data.split("&");

if (speed[i]==undefined){
var display_message:URLLoader = new URLLoader();
display_message.addEventListener(Event.COMPLETE, onLoaded);
function onLoaded(e:Event):void {
var error:Array = e.target.data.split("&");
textbox.text= error[0];
      };

          display_message.load(new URLRequest("error.txt"));
          gotoAndPlay (1,"Scene 1");}//end if

          else
          textbox.text= speed[i];
          };

myTextLoader.load(new URLRequest("database.txt"));
```

The working principle of this method:

i) Create a textbox

ii) Assign a destination text file to read data

iii) Split data read using special character

iv) Display value as arrays

v) Continuously looping from frame to frame

The SWF file is designed in such a way that whenever a button is pressed to monitor the motor speed, a looping back from scene to scene is prompted. This is done to ensure that the action script is being executed continuously so that it will continuously read from the particular text file to get the updated data. Action script 3.0 was used in the Flash design.

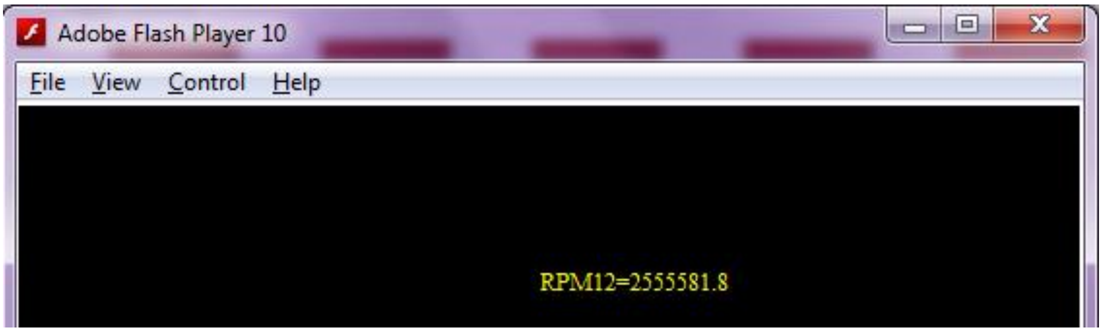

Figure 5.6: Initial design of speed monitoring SWF file

Figure 5.7: Error message during serial-communication failure

5.2.4 Graphical User Interface Design

Using Adobe Flash CS4, Graphical User Interface (GUI) of an electric vehicle on-board intelligent monitoring system has been designed with some desired functions. Temperature monitoring, CPS, BMS, phone calling features and advanced settings can be controlled through this GUI.

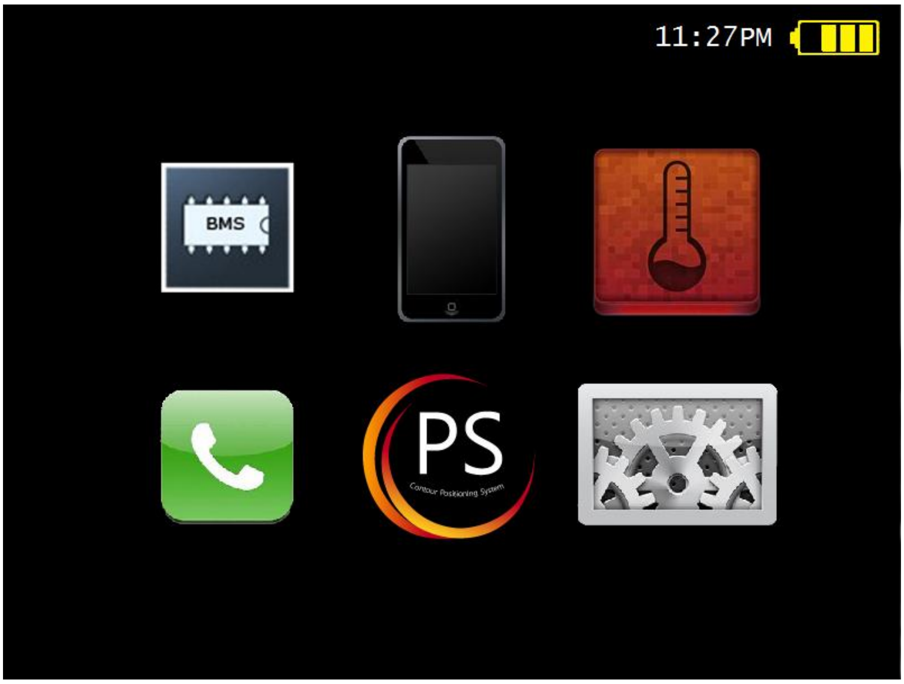

Figure 5.8: Main page of EV control system GUI

This prototype of electric vehicle on-board intelligent monitoring system is designed by combining existing technology and innovate feature such as CPS.

Speed monitoring is included in this design. It is under the section of Monitoring System where the user can monitor the battery level and motor speed. A special logo for CPS has been designed for this prototype GUI.

5.3 Results and Discussion

Figure 5.9: Main page of CPS interface

Figure 5.10: Point of interest selection page

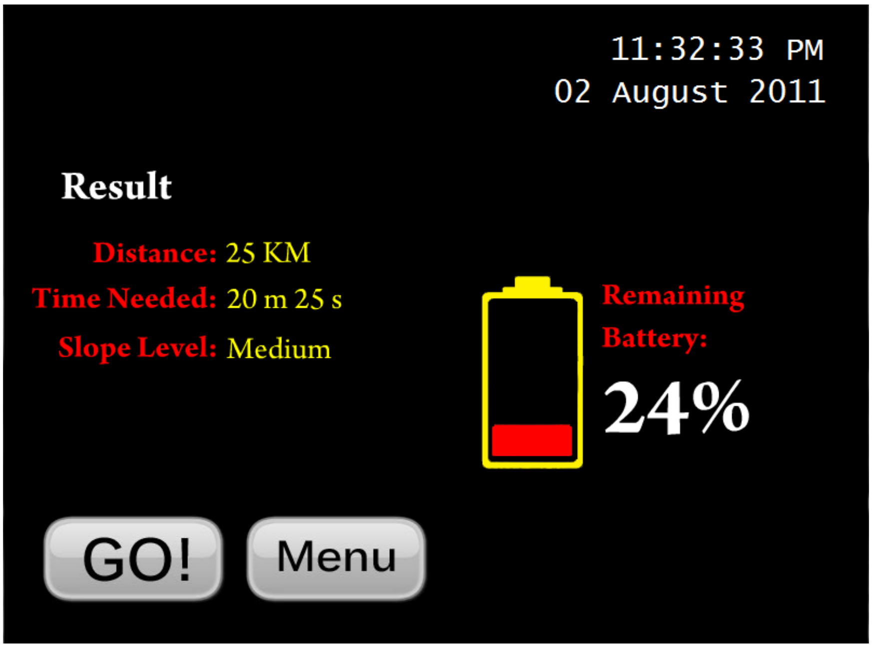

Figure 5.11: Calculation results displaying page

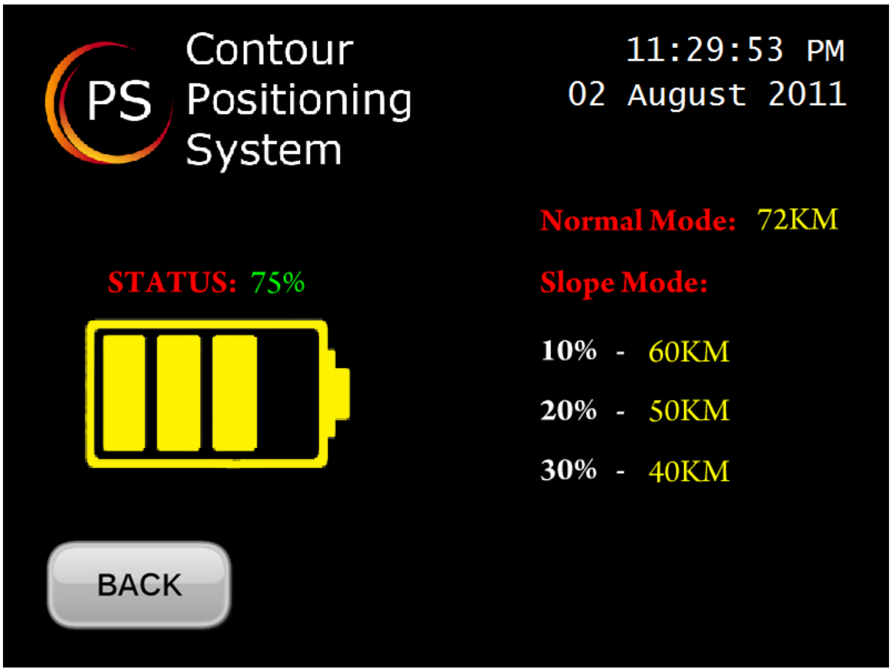

Figure 5.12: Battery status checking page

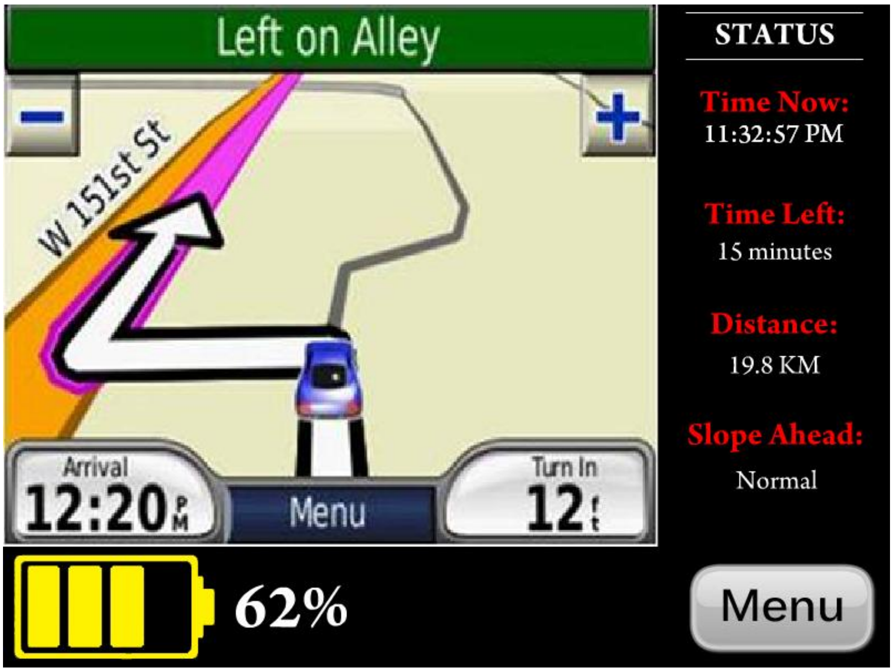

Figure 5.13: Navigation page with CPS results updated

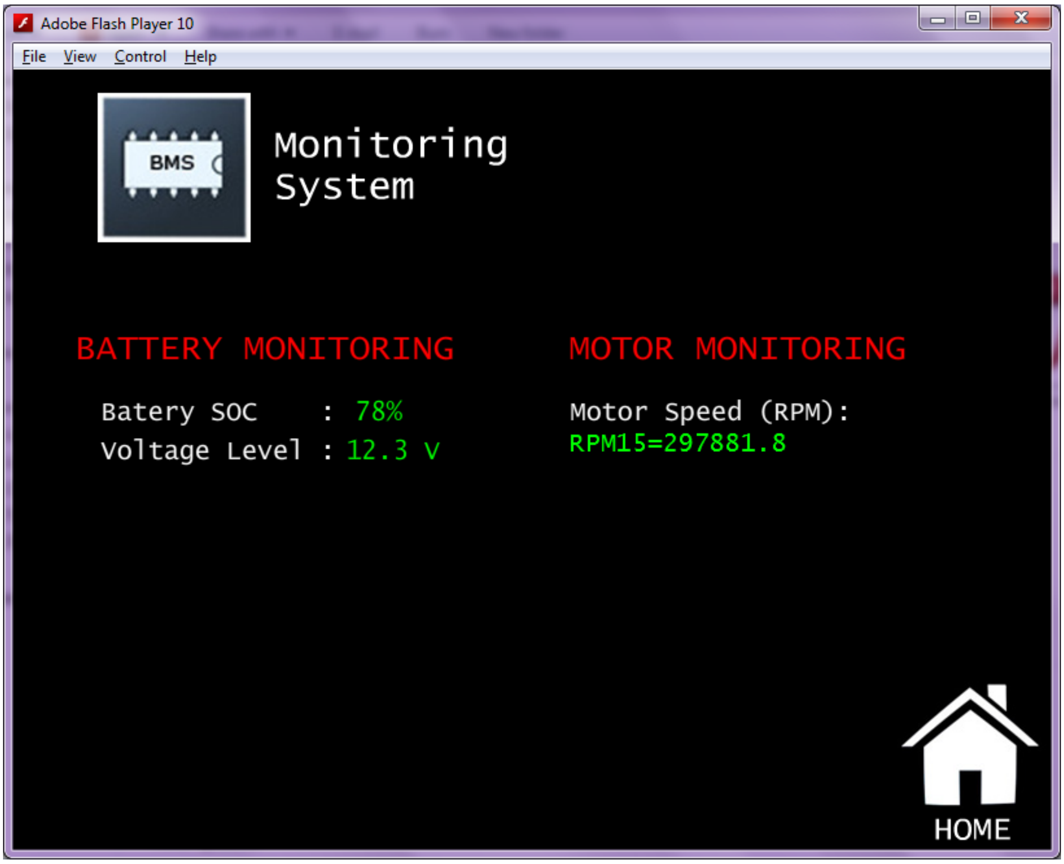

Figure 5.14: Motor monitoring page

As shown in Figure 5.9 to Figure 5.13, the main GUI page with be directed to the CPS page where the user can choose to view current battery status or to choose a point of interest. Once a location is selected, the user will see the calculated remaining battery status under CPS method which considered about the contour condition along the route line selected.

CPS calculation has been used in this GUI design to show how it can be implemented on an EV or even a conventional gasoline-powered car.

As shown in Figure 5.14, the monitoring system page has been done with both battery monitoring and motor speed monitoring. The input to the motor speed monitoring is obtained from a specified text file saved using terminal program (SerialTerm or PuTTY).

5.4 Suggestions for Improvements

Smart phone revolution has brought significant impact to global users. Smart phones with surprising features are equipped with powerful mobile operating system. Two of the famous mobile operating systems are known as iOS and Android.

Smart phone features could be embedded onto the on-board computers in EV, such as the phone calling feature and infotainment feature. For instance, an Android smart phone can be connected to computer using VNC remote control software.

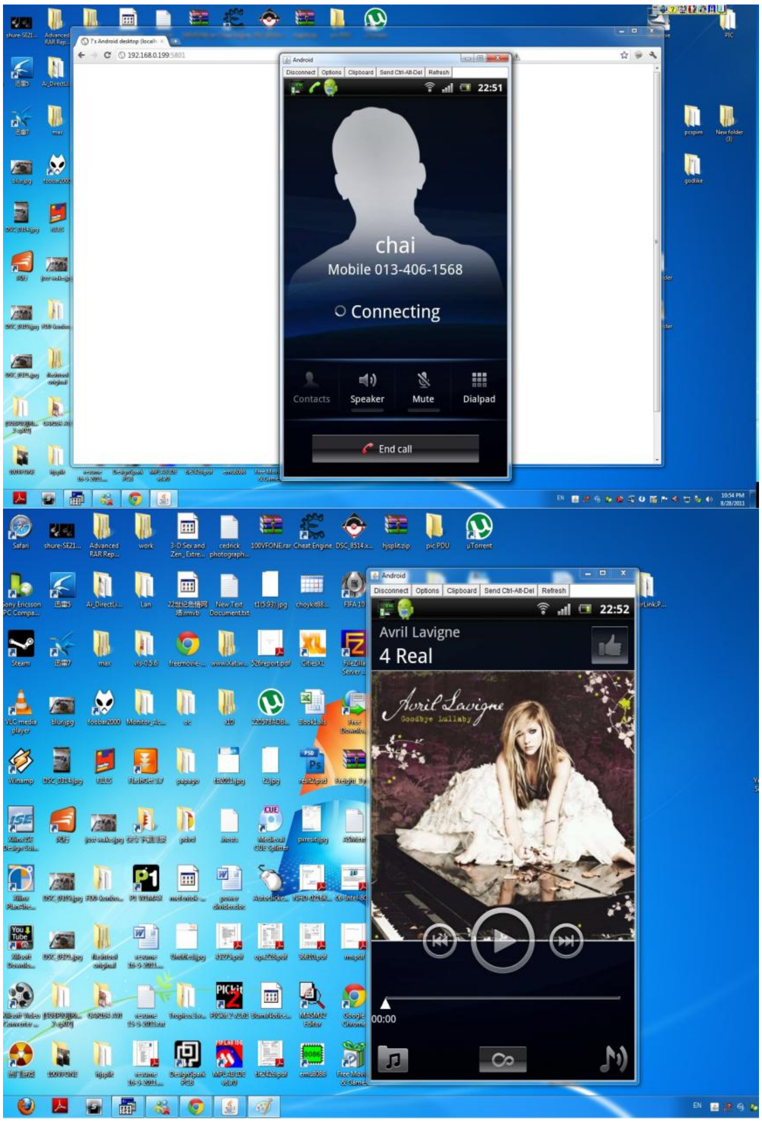

Figure 5.15: Phone calling and media playing feature on computer

CHAPTER 6

COMPETITIONS AND ACHIEVEMENTS

6.1 1MALAYSIA Solar Competition


MYROBOTZ
INNOVATIVE - CREATIVE - ENGINEERED
MOSTI
PUSAT SAINS NEGARA

SIJIL PENYERTAAN

Dengan ini disahkan bahawa

LEOW ENG CHAI
880713-02-5231

telah menyertai

1MALAYSIA SOLAR COMPETITION
(KATEGORI TERBUKA KERETA SOLAR)

Bertempat:

Pusat Sains Negara

Pada:

26 – 29 Mei 2011

KOH SENG YAU
Pengarah Urusan
Myrobotz Enterprise

DR. IRMAWATI RAMLI
Pengarah
Pusat Sains Negara

Figure 6.1: 1Malaysia Solar Competition (Solar Car) certificate

6.2 JamesDyson Award

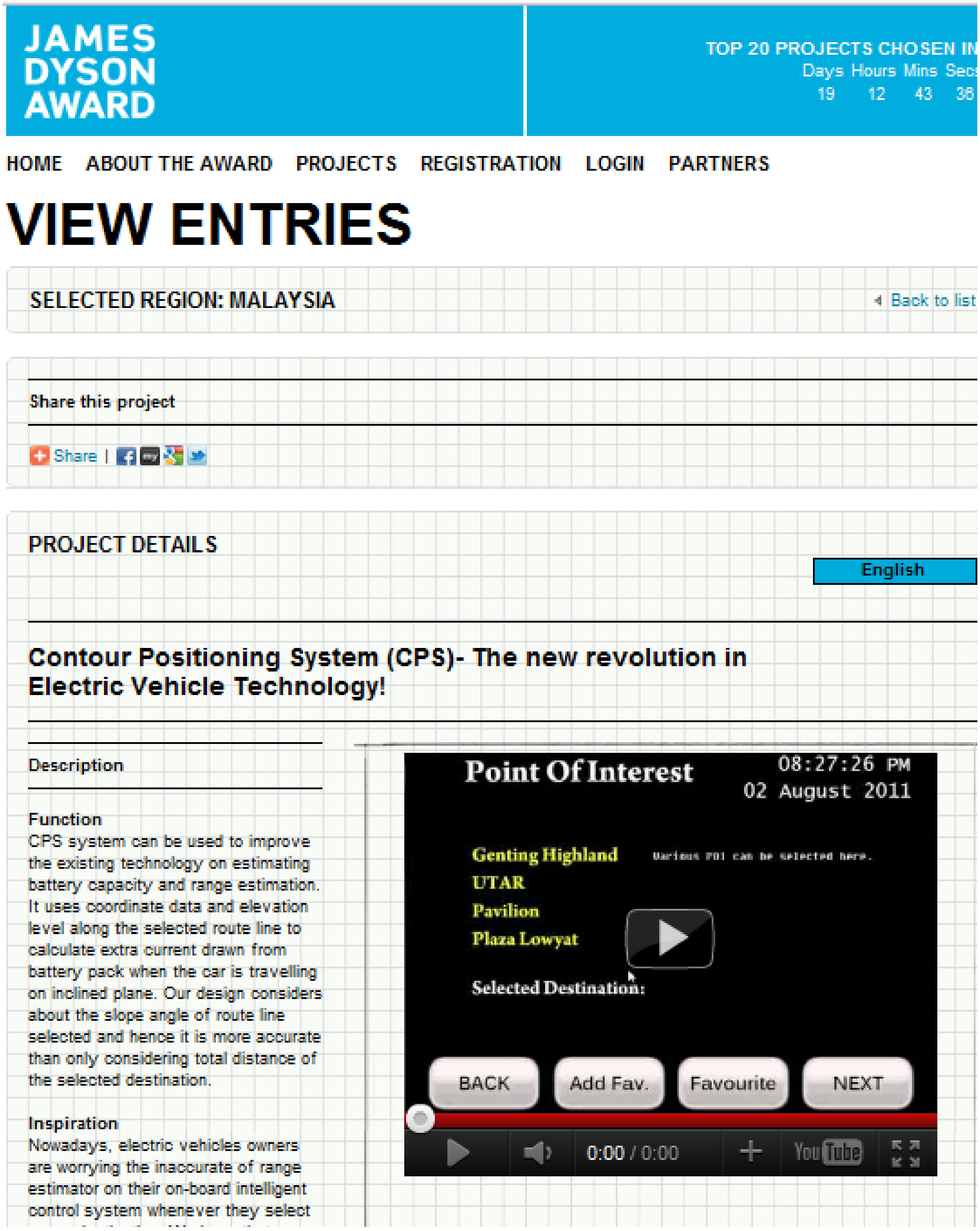

Figure 6.2: JamesDyson Award project listing

- 2nd August: Project submission
- 6th September: Qualified as Malaysia top ten National Finalists
- Current stage: Pending international top 20 teams selection

6.3 Manuscript Submission

Manuscript entitled “Contour Positioning System - New Idea to Enhance Electric Vehicle Battery Capacity Estimation” submission:

i. IEEE (submission accepted)
ii. Elsevier Editorial System (submission accepted)

6.4 MSC Malaysia APICTA Awards 2011

Submission of ‘Development of Electric Vehicle Intelligent Control System (EVICS) prototype’ for the Best of Research & Development category under MSC Malaysia APICTA Awards 2011 shortlisted to final stage presentation.

- Current stage: Pending winner announcement

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

In this project, several modules are added as extra features to an EV control system. The CPS introduced can be a new revolution in the range and battery estimation technology; contour conditions should be considered in order to estimate available battery capacity accurately. A series of CPS calculation is proven to match measured values from inclined plane experiment; some improvements could be made to make the system more reliable.

Motor speed monitoring was done using back-EMF control method; hence it does not use sensors. Using PIC24 as core microcontroller, ADC conversion was done and the RPM calculated from back-EMF could be shown on a LCD display. Using RS-232 serial communication, the motor speed could be monitored through GUI designed using Adobe Flash. Real time monitoring can be achieved by using LoadVars method in Adobe Flash so that the SWF file can continuously read data from a text file.

7.2 Recommendation

Real time kernel and real time operating system shall be created in order to have real time response within microcontroller and computer serial ports. For an EV, data communication for displaying at the on-board display screen shall be kept as real time as possible. The importance of real time condition will only be realized during crucial condition; hence it should be implemented for the EV drivers' safety purpose.

RS-232 communication protocol could be replaced by Universal Serial Bus (USB) standard in order to have higher speed transmission. USB connection is also easier to be carried out by end users.

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APPENDICES

APPENDIX A: Graphs

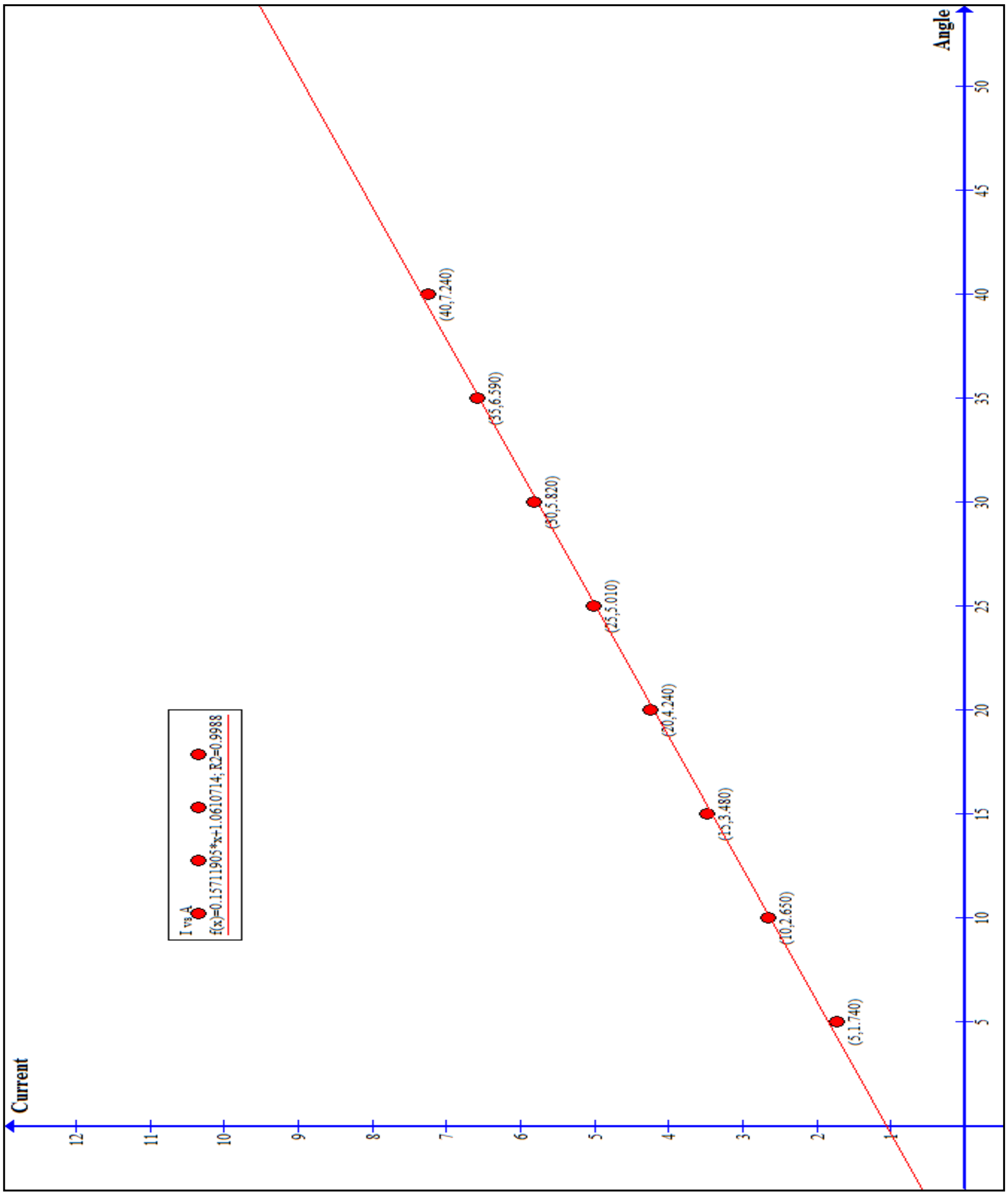

Figure 7.1: Current versus Angle graph plotting

APPENDIX B: Computer Programme Listing

```
//Main Program coding

#include <P24FJ64GA002.H>
#include <stdio.h>
#include <string.h>
#include "LCD.c"
#include "adc.c"
#include "function.h"
#include "UART_KC.c"

_CONFIG1(JTAGEN_OFF & BKBUG_OFF & FWDTEN_OFF)
_CONFIG2(FCKSM_CSDCMD & OSCIOFNC_ON & POSCMOD_NONE &
FNOSC_FRC)

void main(void)
{char speed[7];
char volt[3];
char counter[20];

float value,value1,temperature;
int loop;
int ct=0;

lcd_init();
initU1();
```

```
if(_RB1=1)
{
for (ct=0;ct<1000000;ct++){
ADCInit();            // Initialize the A/D converter
ADCStart();                              // Turn ADC on

while(!_AD1IF);
          _AD1IF = 0;

value=0;//value is float type
value = ADCAvg();                        // Take average of 16 samples
value = value*3.3/16384;                 // Formula of calculate input voltage; max emf
is 3.3V

value+=0.82;                             //compensate for voltage drop
value1 = value*12000/3.3;                //conversion of motor speed 0~9V >> 0~2.88;

        if (value1<2990){
        putsU1 ("0");
        putsU1 ("&");
        msdelay(10);

        lcd_clear();
        lcd_gotoxy(0,1);                 //display RPM value at first line of LCD
        lcd_puts("RPM: ");
        lcd_gotoxy(5,1);
        lcd_puts("0");
        msdelay(550);
                                         }//end if

        else{
        sprintf(speed, "%.1f", value1); //convert float (value1) to string
        putsU1 (speed);                  //transmit speed value to serial port
        putsU1 ("&");                    //transmit characeter "&" to serial port
```

```
        msdelay(10);

        lcd_clear();
        lcd_gotoxy(0,1);                    //display RPM value at first line of LCD
        lcd_puts("RPM: ");
        lcd_gotoxy(5,1);
        lcd_puts(speed);
        msdelay(550);
                }//end else

        }//end for loop

}//end if loop


else
lcd_clear();

}//end main loop




//UART library for serial communications

#include <p24fj64ga002.h>

/***************************************************
*********Initialization for UART settings**********
***************************************************/
//call the function initU1() to set up UART port for data transmission to PC
//Using MAX232 connect T1IN to RP6 and R1OUT to RP5

void initU1(void)
{
```

```
        RPINR18bits.U1RXR=5;      //set pin14 as U1RX
        RPOR3=0x0003;             //set pin15 as U1TX
        U1BRG=25;                 // baud rate=9600 for 8MHz FRC
        U1MODE=0x8000;            //enable UART
        U1STA=0x0400;             //enable transmission
        IFS0bits.U1TXIF=0;        //ensure TX1 interrupt flag is 0
}

/**************************************************
*******Transmission of data in string************
**************************************************/
int putsU1 (char *s)
{
        while (*s)
        {
        delay();
        transmitU1(*s++);
        }
}


/**************************************************
*****Tansmission of data from U1TX(integer)********
**************************************************/

int transmitU1(int c)
{
        U1TXREG=c;                        //move the integer to TX1 register
        IFS0bits.U1TXIF=0;        //ensure TX1 interrupt flag is 0
        while (!IFS0bits.U1TXIF);
        return c;
}
```

```
/*************************************************
*******************Timing delay********************
*************************************************/
//provide delay for the clock to stable after power up
//provide delay for the transmission to complete
void delay()
{
	unsigned char i,j;

	for(i=0;i<255;i++)
	for(j=0;j<100;j++);
}

/*************************************************
******Function provide newline for UART************
*************************************************/
void newline()
{
	delay();
	transmitU1(10);		//go to new line and return
	delay();
	transmitU1(13);
}


/*************************************************
**************Data receive to U1RX****************
*************************************************/
char getU1()
{
	while(!U1STAbits.URXDA);
	delay();
	return U1RXREG;
}
```

//LCD initialization code

```
#include <P24FJ64GA002.H>
#include "lcd.h"


/*************************************************/
/* msdelay(x)                              */
/* Delay for x milliseconds.               */
/* Note delay is only approximate .        */
/* Max value for x is 65536 i.e. 65.536 seconds   */
/*************************************************/
void msdelay(unsigned int x)
{
   unsigned int delval;
   while(x--)
   {
      delval =794;  //msdelay(1)= delay of 1.000250mSecs
      while(delval--)
         ;
   }
}

/*************************************************/
/* lcd_init()                              */
/* Initialise the LCD                      */
/*************************************************/
void lcd_init()
{
   /* 0x28 - 4 bit mode
     0x06 -
     0x0c -
   */
   static BYTE lcd_init_data[] = { 0x28,0x06,0x0c };
```

```
    BYTE i;

    AD1PCFG |= 0xffff;//0x003C;
    TRISB &= 0x10F0;//0xFFC0;
    TRISA &= 0x0000;
    E = 0;
    RS = 0;
    msdelay(20);
    /* Ensure LCD is in known state */
    for( i = 0; i < 3; i++)
    {
       lcd_write_nibble(0x03);
       msdelay(5);
    }

    /*Set LCD to 4-bit mode */
    lcd_write_nibble(2);
    msdelay(1);

    /* Configure LCD */
    for( i = 0; i < 3; i++)
    {
       lcd_write_byte(lcd_init_data[i]);
    }
    lcd_clear();
}

/***************************************************/
/*  lcd_clear()                              */
/*  Clear LCD to all spaces                  */
/***************************************************/
void lcd_clear()
{
    lcd_write_control_byte(CLEAR_LCD);
```

```
   msdelay(5);
}

/*************************************************/
/* lcd_gotoxy(x,y)                              */
/* Position cursor at column x, line y.         */
/* For a 2 line 16 character display            */
/* x = 0 to 15, y = 0 or 1                      */
/*************************************************/
void lcd_gotoxy(BYTE x, BYTE y)
{
   BYTE pos = 0x80;

   if ( (x < 16) && (y < 2) )
   {
         if (y > 0)
            {
            pos += 0x40;      // position for second line
         }
            pos += x;          // add offset
            lcd_write_control_byte(pos);
         }

}

/*************************************************/
/* lcd_putchar(x)                               */
/* display character x on LCD at cursor location. */
/*************************************************/
void lcd_putchar(char x)
{
   lcd_write_data_byte(x);
}
```

```
/*************************************************/
/* lcd_puts(s)                                  */
/* Display string s on LCD at cursor location.    */
/*************************************************/
void lcd_puts(const char *s)
{
   while(*s)
      lcd_write_data_byte(*s++);
}

/*================================================*/
/*        END OF PUBLIC FUNCTIONS                */
/*================================================*/

/**********************************************
          The following functions should not need
          to be called by a user program
**********************************************/
static void lcd_write_nibble(BYTE x)
{

   LATA = ((LATA & 0xFFF0) | x);
   E = 1;
   E = 1;
   E = 0;
}

static void lcd_write_byte(BYTE x)
{
   BYTE temp;
   temp = (x >> 4) & 0x0f;
   lcd_write_nibble(temp);
   temp = x & 0x0f;
   lcd_write_nibble(temp);
```

```
    msdelay(1);
}

void lcd_write_control_byte(BYTE x)
{
    RS = 0;
    lcd_write_byte(x);
}

void lcd_write_data_byte(BYTE x)
{
    RS = 1;
    lcd_write_byte(x);
}


//ADC initialization code

ADCInit()
{
AD1CON1 = 0x00E4;
AD1CON2 = 0x003C;
AD1CON3 = 0x0D09;
AD1CHS=0x0102;
AD1PCFG=0xFFFB;
AD1CSSL=0x0000;
}


ADCStart()
{
  _ADON = 1;     // Turn on the A/D converter
}
```

```
ADCAvg()
{
	unsigned long int temp;


temp =		ADC1BUF0 + ADC1BUF1 + ADC1BUF2 + ADC1BUF3 +
		ADC1BUF4 + ADC1BUF5 + ADC1BUF6 + ADC1BUF7 +
		ADC1BUF8 + ADC1BUF9 + ADC1BUFA + ADC1BUFB +
		ADC1BUFC + ADC1BUFD + ADC1BUFE + ADC1BUFF;

return (temp);
}
```