CONTOUR POSITIONING SYSTEM (CPS) – A NOVEL RANGE PREDICTION TECHNIQUE FOR ELECTRIC VEHICLES USING SIMULATIONS

GAN YU HAN

MASTER OF ENGINEERING SCIENCE

FACULTY OF ENGINEERING AND SCIENCE
UNIVERSITI TUNKU ABDUL RAHMAN
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By

GAN YU HAN

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ABSTRACT

CONTOUR POSITIONING SYSTEM (CPS) – A NOVEL RANGE PREDICTION TECHNIQUE FOR ELECTRIC VEHICLES USING SIMULATIONS

Gan Yu Han

The Contour Positioning System (CPS) is a novel research idea proposed for electric vehicles (EV) to calculate and estimate accurately the amount of battery energy needed(%) to reach a desired destination. This new idea takes into account the extra battery energy needed for an EV to travel on a slope especially during uphill conditions. For example, an EV moving uphill 10 km will definitely consume more battery energy compared to moving 10 km on a straight road highway. Conventional distance estimation system could not tell the difference mentioned above. The techniques of CPS are by extracting the distance and elevation profile from Google Earth using Python programming and simulate the distance estimation results using MATLAB. The focus of this research is on the calculations and simulations using MATLAB. Finally, the objective of this research is to improve the current battery energy estimation system in EVs by taking into consideration road slope angles and elevation profiles so that users can reach their desired destination safely.

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FACULTY OF ENGINEERING AND SCIENCE

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Date: __________________

SUBMISSION OF DISSERTATION

It is hereby certified that ***GAN YU HAN*** (ID No: ***11UEM06777***) has completed this dissertation entitled "*CONTOUR POSITIONING SYSTEM (CPS) – A NOVEL RANGE PREDICTION TECHNIQUE FOR ELECTRIC VEHICLES USING SIMULATIONS*" under the supervision of Dr. CHEW KUEW WAI (Supervisor) from the Department of Electrical and Electronic Engineering, Faculty of Engineering and Science , and Ir. Dr. LIM YUN SENG (Co-Supervisor) from the Department of Electrical and Electronic Engineering, Faculty of Engineering and Science.

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Yours truly,

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(*Gan Yu Han*)

APPROVAL SHEET

This dissertation entitled "**CONTOUR POSITIONING SYSTEM (CPS) – A NOVEL RANGE PREDICTION TECHNIQUE FOR ELECTRIC VEHICLES USING SIMULATIONS**" was prepared by GAN YU HAN and submitted as partial fulfillment of the requirements for the degree of Master of Engineering Science at Universiti Tunku Abdul Rahman.

Approved by:

____
(Associate Prof. Dr. CHEW KUEW WAI)
Date:
Supervisor
Department of Electrical and Electronic Engineering
Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

____
(Associate Prof. Ir. Dr. LIM YUN SENG)
Date:
Co-supervisor
Department of Electrical and Electronic Engineering
Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

DECLARATION

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

Name **GAN YU HAN**

Date ______________________________

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LIST OF ABBREVIATIONS

CPS	Contour Positioning System
km	kilometres
EV	Electric Vehicle
GPS	Global Positioning System
EVICS	Electric Vehicle Intelligent Control System
km/h	kilometres per hour
rpm	revolutions per minute
ICE	internal combustion engine
GUI	Graphical User Interface
LCD	liquid crystal display
Li-ion	Lithium-ion
etc	et cetera / and so forth
et al.	and others
kWh	kilo Watt hours
NiCad	Nickel-Cadmium
NiMH	Nickel-Metal Hydride
PHEV	plug-in hybrid electric vehicle
BEV	battery electric vehicle
HEV	hybrid electric vehicle
P/E	power-to-energy
BMS	Battery Management System
SOC	state of charge
DOD	depth of discharge
SOH	state of health

CAN	Controller Area Network
HVAC	heating, ventilation, and air conditioning
i. e.	for example
kW	kilowatt
AC	alternating current
DC	direct current
V	volt
DEM	digital elevation model
SRTM	Shuttle Radar Topography Mission
IEEE	Institute of Electrical and Electronics Engineers
TPM	Technology Park Malaysia
LRT	Light Rail Transit

CHAPTER 1

INTRODUCTION

1.1 Introduction to CPS

The Contour Positioning System (CPS) works by extracting road contour distance (in km) and elevation heights (in meters) data from Google Earth's elevation profile and using them to produce the road contour slope angles (in degree). Using software, some programming and formulas, those parameters obtained can be used to provide an estimation of the amount of battery energy needed. For example, this system will indicate to the user that driving 100km from point A to point B requires 50% of the EV's battery energy. Therefore, the user will know if the remaining battery energy is enough to reach the desired destination.

This system is accurate and unique because it includes the road slope angles which drains different amount of battery energy depending on the degree of the slope. For example, driving up a hill for 100km in a 10% slope uses a lot more battery energy compared to driving 100km on a normal 0% straight highway.

Both data collections and real-time validations were done using the latest Proton Saga EV specifications and technical data to clarify the experimental results. The new Saga EVs are the ones sent by Proton to the

Malaysian government for the test fleet. A total of three Proton Saga EVs were sent for fleet testing and expected to be commercialised in Malaysia (Bernama, 2011).

By performing a series of battery capacity calculations, CPS can provide higher precision of remaining battery capacity for reaching a desired destination, making it an accurate battery energy estimation system for an EV compared to the current distance estimation system available in the market which could not tell the difference between moving 10 km uphill and 10km on a straight road. CPS can be integrated into current GPS to provide an indication and suggestion to the nearest charging station when the battery energy is getting low while the user is driving.

This new distance estimation method can be proposed to car manufacturers and it is possible to implement the CPS into future electric cars.

1.2 Background of Study

The CPS is part of a complete software which comes from the Electric Vehicle Intelligent Control System(EVICS) project where the EVICS is a 2-in-1 system for an Electric Vehicle(EV) which consist of Monitoring System for the front seat driver and Infotainment System for the rear seat passengers. The Monitoring system consists of battery voltage, current and temperature monitoring modules, battery energy status(%), distance left(km), km/h meter, rpm meter, offline Global Positioning System(GPS), auto-driving or auto-cruising functions, online GPS and Contour Positioning System(CPS). The Infotainment System consists of music and movie player, internet and web streaming (Google), social networking applications (Facebook, Twitter, LinkedIn, Blogspot), games (Angry Birds), video streaming (Youtube), and many more. The Infotainment System can also be implemented into the conventional ICE vehicles. Apart from that, the EVICS can also be controlled using a remote control like any other audio player devices in a car.

Figure 1.1: EVICS front seat Graphical User Interface(GUI) display

Figure 1.2: EVICS rear seat Graphical User Interface(GUI) display

The EVICS uses the Linux Ubuntu operating system because it is easily accessible and stable. The EVICS operates both the Monitoring System at the driver seat and the Infotainment System at the rear seat where both systems are operating separately on two capacitive LCD touch screens, mice and keyboards on any multiple processor platforms.

The EVICS is different from those in the market because it is a computer system that can also be installed into any engine vehicle. The EVICS is also isolated and not connected to any existing system in the car. All it needs is tapping power in parallel from the 12V lead-acid battery to operate; therefore the Infotainment System can be installed into any current engine vehicle. However in ICE vehicles, certain modules from the Monitoring System will be disabled such as the battery voltage, current and temperature monitoring modules and CPS.

The In-vehicle mobile Wi-Fi system is also an advantage and unique as it provides internet connection to the users when the vehicle is moving on the road. Compared to handheld smartphone internet data plans, this mobile Wi-Fi system has larger viewing size LCD capacitive touch screens for comfortable web surfing, video streaming and social networking on the go. With the Wi-Fi system, the EVICS can be controlled and monitored remotely using external computers, laptops and Android based smartphones because it has a build-in modem router. This feature is important for external computers and laptops to connect wirelessly to the EVICS platform to monitor the performance of the car. Therefore, engineers and technicians can switch ON the modem router to verify and determine problems with the EV system remotely without conducting the conventional hands-on approach.

The EVICS also has a 3-in-1 function that targets users, manufacturers, and the service sector. For users, the EVICS has a comprehensive rear seat Infotainment System that can connect multiple independent users (front seat and rear seat). For car manufacturers, they can access log files and data extraction functions to share common problems and discussions regarding electric vehicles with worldwide international automobile manufacturers. For the service and technical side, mechanics and foremen can remotely access and monitor the EVICS system for repair, analysis and troubleshooting work.

For an EV, the main problem is the finite supply of energy from the lithium-ion battery pack. Recognising this as a major problem in an EV, the EVICS has three methods of energy generations to further supply the vehicle battery with more energy by tapping from the natural surrounding resources available such as wind and gravity. The three energy generator systems are wind energy generation system, regenerative braking system and regenerative downhill system (Gan Yu Han, 2012). The wind energy generation system operating principle is when the vehicle is moving, the wind drag will move fans which are coupled to generators to produce a small amount of current to charge the battery pack. The regenerative braking system is one where energy is supplied to the battery pack whenever the brake is applied. Mechanical energy will be converted back into electrical energy that can be reinstalled back into the battery pack.

1.3 Research Objectives

The main goal of this research is to develop a new battery capacity estimation system for electric vehicles(EV) which is known as Contour Positioning System(CPS). CPS will calculate the remaining battery capacity and provide accurate estimation of the amount of battery energy needed(%) for the user to drive to a desired destination. The significant contribution of this research is this system not only considers the distance, but also takes into account the positive slopes and elevation of the path from the origin or current location to destination. This method requires an approach that exploits à-priori consumption features of the vehicle and GPS-Google Earth elevation profile information.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Electric Vehicles

Electric vehicle technology is now in its third century of development and is likely to advance rapidly in the coming years.

Electric trains are widely used and modern high-speed trains are competitive with air travel in terms of journey speed over shorter land routes. In energy terms they use less than 10% of the fuel per passenger kilometre than air transport.

Electric vehicles (EVs) have not achieved the market and commercial success that internal combustion engine (ICE) vehicles have. However, battery technology such as Lithium-ion batteries has now developed to the point where electric vehicles are being commercially produced. Future battery developments are likely to accelerate the use of electric road vehicles in the next few years and it will slowly but eventually become a future trend.

Small electric vehicles such as golf buggies and personnel carriers in airports have become well established. Electric bicycles and motorcycles are becoming increasingly popular and are considered one of the fastest ways to move about crowded cities.

Potential environmental benefits which can result from the use of electric vehicles are substantial when the vehicles use electricity that is generated from sources which use highly efficient modern generating stations or which use nuclear, sustainable or renewable energy. Environmental benefits include zero exhaust emissions in the vicinity of the vehicles, reduced dependence on fossil fuels and reduced overall carbon emissions.

Electric vehicles are becoming increasingly important and popular because they reduce noise and pollution, and also reduce our dependence on oil. More importantly, electric vehicles will help to reduce our carbon footprints and emissions. To ensure that zero release of carbon dioxide into the atmosphere, the energy used in electric vehicles must be produced from non-fossil-fuel sources like alternative renewable energy and nuclear energy.

It is estimated that we have approximately 40 years of oil supply left at our current usage rates. In terms of economics, increasing scarcity will result in significant price increases and the use of oil and other fossil fuels will not be economically viable in the long run. Therefore, oil will be conserved as usage will decrease. Oil could also be produced from alternative fossil fuels like coal. Usually, oil produced using this method was approximately 10% more expensive, but with the current prices of oil, production from coal is becoming more economically viable. Although coal is still a finite resource, it is more abundant than oil and there is in excess of around 100 years of coal left.

Global warming has always been a main headache and problem around the world. It results mainly on the release of carbon dioxide into the atmosphere when fossil fuels are burnt where it will give rise to a range of problems including rising sea levels and climate change which may flood and submerge many of the world's coastal cities into the sea.

Electric trains have long been well developed and widely used. However, the production of electric vehicles by automotive industries and use of those vehicles by consumers are only starting to pick up a few years ago. Whereas smaller range electric vehicles produced for niche markets such as golf buggies, electric motorcycles, and electric bicycles are widely used, electric road vehicles and cars are not. Moreover, electric vehicles face problems that internal combustion engine (ICE) vehicles do not and have huge successes which are very easy to refuel, fast refuel time and longer driving distance and ranges.

It is utmost important that the design principles of an electric vehicle and the relevant environmental and technological problems are thoroughly sort out and understood (Larminie et al., 2012).

Table 2.1 shows some of the common electric vehicles that are available in the market and some of the common characteristics that they have. All the EVs listed in the table runs on lithium-ion battery packs to produce an accurate and compatible comparison between one to the other.

Table 2.1: Electric vehicles running on lithium-ion battery specifications

	Electric Range km	Battery Energy kWh	Energy Density Wh/kg	Vehicle Weight kg	Battery Weight kg	Vehicle to battery weight ratio
Proton Saga EV	120	15.9	105	1,148	151	7.60
Nissan Leaf	160	24	140	1,535	171	8.98
Mitsubishi i-MiEV	100	16	109	1,170	147	7.96
Tesla Roadster	394	56	121	1,235	449	2.75
BMW Mini E	160	35	135	1465	259	5.66
Ford Focus EV	122	23	100	1,674	295	5.67

2.2 Introduction to Battery Development: Lithium-ion Batteries Technology

- 1912: First experiments with Lithium Batteries
- 1980: Research for Lithium Ion Batteries started
- 1991: Sony sold the first Lithium Ion Battery
- 1996: The Lithium Polymer Battery was invented
- 2006: Sony recalled 10 million batteries
- 2007: Nokia recalled over 46 million batteries

Figure 2.1: Lithium-ion battery history

Figure 2.1 shows a brief lithium-ion battery history since 1912 till 2007 (Larminie et al., 2003). Since the late 1980s, rechargeable lithium cells and batteries have come onto the market. They offer much higher energy density compared to other rechargeable batteries such as lead acid batteries, although usually at a higher cost. It is a well-established feature in laptop computers and mobile phones where lithium rechargeable batteries are specified, rather than the lower cost NiCad or NiMH cells.

Lithium-ion batteries are predicted to become the most popular battery source for all the ranges of electric vehicles from plug-in, hybrid to fully powered battery EVs in the future. Although other types of batteries such as lead-acid and nickel-metal hydride (NiMH) will continue to retain considerable market share for now, lithium-ion batteries are expected to dominate the market by 2017 (Deutsche Bank, 2009). Compared to other batteries used in EVs, lithium-ion batteries have the highest power density making it an ideal source of power and energy. The cost of production is also rapidly decreasing making it affordable for the consumer market. (Lowe et al., 2010).

EVs use an electric motor which is powered by a set of battery pack to power the vehicle. Batteries used in EVs need higher energy capacity due to limited amount of charging stations and for longer driving distances, so EVs have the lowest power-to-energy (P/E) ratio factor. The battery pack is usually fully charged and discharged (deep cycles) and has a lifetime of approximately 1,000 charging cycle. The battery size for EVs is also usually larger than those for PHEVs or HEVs because they run on only the electric motor. For example, the Nissan Leaf has a 24-kWh capacity (Nissan USA, 2012). Lithium-ion battery packs for compact EVs will use 1,800 to 2,000 cells (METI, 2009). Some of the companies that manufacture lithium-ion batteries for EVs are A123 Systems, Thunder Sky, LG Chem, Automotive Energy Supply Corp., Hitachi, Lithium Energy Japan etc. Valence Technology Inc. (VLNC), a former maker of batteries for electric vehicles filed Chapter 11 in the U.S. Bankruptcy Court in July 2012, sought bankruptcy protection from creditors, saying it plans to complete its restructuring this year (Bathon, 2012).

2.2.1 The Lithium Polymer Battery

The lithium polymer battery uses lithium metal at the negative electrode and a transition metal intercalation oxide for the positive electrode. In the chemical reaction shown below, lithium reacts with metal oxide to form a lithium metal oxide while releases energy at the same time. However, the chemical reaction is reversed when the battery is recharged. Therefore, lithium is both a reactant and mobile ion that moves through the electrolyte. The overall chemical reaction is shown as below:

$$xLi + MyOz \longleftrightarrow LixMyOz$$

The solid lithium metal at the negative electrode has been a cause of problems with this type of cell; there are safety issues and sometimes a decrease in performance due to passivation. Therefore, they have been largely superseded by the lithium ion battery.

2.2.2 The Lithium Ion Battery

The lithium ion battery was introduced during the early 1990s. It uses a lithiated transition metal intercalation oxide for the positive electrode and lithiated carbon for the negative electrode. The electrolyte is usually a liquid organic solution or a solid polymer. Electrical energy is produced from the combination of lithium carbon and lithium metal oxide to form carbon and lithium metal oxide. The overall chemical reaction is shown below:

$$C_6Li_x + M_yO_z \longleftrightarrow 6C + Li_xM_yO_z$$

The essential features of the battery are illustrated in Table 2.2 below. An important factor about lithium ion batteries is where an accurate control of voltage is needed when charging the lithium cells. If it is slightly too high, it can possibly damage the battery and if it is too low, the battery will be insufficiently charged. Suitable commercial chargers are being developed along with the battery (Larminie et al., 2003).

Table 2.2: Nominal battery parameters for lithium ion batteries

Specific energy	**90 Wh.kg $^{-1}$**
Energy density	153 Wh.L $^{-1}$
Specific power	300 W.kg $^{-1}$

Nominal cell voltage	3.5V
Amphour efficiency	Very good
Internal resistance	Very low
Commercially available	Only in very small cells, not suitable for electric vehicles
Operating temperature	Ambient
Self-discharge	Very low, ~10% per month
Number of life cycles	>1000 times
Recharge time	2-3 hours

The lithium ion battery has a weight advantage over other battery technologies and this makes it a highly attractive feature for electric vehicles. For example, the specific energy is approximately three times of lead acid batteries and this could provide the vehicle with a very reasonable range. However, larger size lithium batteries are currently expensive, and only when a commercial company has set up a mass production line which can produce lower-cost lithium ion batteries at larger quantities due to economics of scale will their potential be fully realised. Currently in year 2013, many electric and hybrid vehicles have been produced using lithium-based batteries such as the Honda Civic Hybrid (3rd Generation), Honda CR-Z, Toyota Prius Plug-in Hybrid, Tesla Roadster, Tesla Model S, Proton Saga EV, Mitsubishi iMiEV, Nissan Leaf etc.

Although research continues on radically different electro-chemistries, it is difficult to see these replacing Li-ion technologies in the foreseeable future. It is more likely that further development and improvement of Li-ion will continue for many years. For example, the increasing importance of EV technology has led to development of new electrode materials for Li-ion cells such as lithiated iron phosphate for the cathode and titanium oxide for the anode. The new range of “nano-structured” electrode materials is currently being actively investigated and this will help in the quest for higher power cells and batteries for motorised applications where very large electric currents are required (AGM Batteries, 2009).

To conclude, there have been several key developments and improvements when it comes to lithium-ion battery technology for the past few decades. Advances are happening in the lithium-based battery technology is largely due to and driven by the consumer electronics industry. These advances allow full-sized, highway-capable EVs to be propelled with a single charge as conventional ICE vehicles move on a single tank of petrol. Lithium batteries have also been made safer and can be recharged in a much shorter time compared to before and now last longer. The production cost of these lighter, higher-capacity lithium batteries is also gradually decreasing due to economics of scale and as the technology matures. Therefore, production volumes are expected to increase as well due to higher demands. Rechargeable lithium-air batteries potentially offer increased range over other types and are a current hot topic for research at the moment.

2.3 EV Battery Management Systems

With the gradual consumption of the Earth's petroleum energy, energy saving and environmentally friendly electric vehicle (EV) technology research has become an important research direction of the national auto companies. The Battery Management System (BMS) is a key component of the EV technology research and it has played an important significance in the EV industry. A battery management system (BMS) is any electronic system that manages a rechargeable battery such as by protecting the battery, calculating secondary data, reporting that data, monitoring its state, controlling its environment, and/or balancing it.

The main tasks of BMS are the acquisition of the battery pack voltage, current and temperature information, State of charge (SOC) or also known as depth of discharge (DOD) to indicate the charge level of the battery, State of health (SOH), a variously defined measurement of the battery's overall condition, other battery information and data processing, intelligent charging process control, coolant flow for air or fluid cooled batteries and other functions. Compared with other types of commonly used lead-acid batteries and nickel cadmium batteries, lithium-ion battery has many advantages such as huge energy density, fast charging and discharging, no environmental pollution etc. However, lithium-ion battery has a large number of EV battery pack and special security requirement, so the entire battery pack will have a large number of measurement points to install with serious safety hazard and great trouble to commissioning.

One of the methods of communication used in an EV BMS is by using the CAN(Controller Area Network) where it is a serial data communication protocol, with high reliability, real-time, simple structure and so on. For the study of pure electric cars with lithium-ion battery pack, the structural features and functional requirements, a reliable method of control system designed can be based on the CAN bus. The distribution EV battery charging system can monitor the battery's voltage, charge and discharge current and the temperature of battery pack online to achieve a coordinated control and optimize charging.

An important constraint to the effective performance and reliability of the battery is its unpredictable internal resistance variation along the driving cycle. Temperature has a considerable effect on this internal resistance and thus the BMS needs to monitor cell and battery pack temperature in accordance with the state-of-charge to prevent thermal runaway. Li-ion batteries offer a very reliable solution to the EVs energy and power density demands and thus need to have a good thermal management system in order to enhance their performance (Sen, 2009).

Another main concern and features that can be included into a BMS is by improving the service life of lithium battery and guaranteeing the safety of the system as a whole based on optimizing the process of charge, or discharge of lithium battery. An example of a BMS implementation is as below:

-Firstly, distribution method is adopted in the BMS to collect the temperature and voltage of the battery.

-Secondly, stage management is given to avoid over charge, or discharge of battery.

-Thirdly, based on a microprocessor (LPC11C14), the charging device is designed.

-Finally, simulations and experiments are provided to show usefulness and effectiveness of the proposed methods.

No BMS solution is available on the market at a cheap price because of the required voltage level and performance. Therefore, some of the important features that a dedicated battery management system should include are high capability of energy storing in braking conditions, charge equalization, overvoltage and undervoltage protection and, obviously, battery SoC monitoring and information in order to optimize autonomy instead of performance or vice-versa (Ru et al., 2012).

To conclude, there are many journals and patents produced on the research of Battery Management Systems in an EV. There is a lot of focus being aimed towards the development of BMS but not many on an accurate distance estimation system in an EV. There is no doubt that BMS plays an important role in the development of an electric vehicle and it is a crucial part to further develop an accurate distance estimation system and here is where the CPS comes into the picture. The BMS needs to provide accurate real-time parameters such as voltage, current and temperature readings, lithium-ion SOC values etc for an accurate calculation of results in the distance estimation system of an EV. Both systems, the BMS and CPS must work together hand in hand closely to produce a comprehensive and reliable distance estimation system for future EVs.

2.4 Current Techniques and Method Used in Distance Estimators

Remaining driving range prediction is especially important for EVs as discussed in the paper Remaining Driving Range Estimation of Electric Vehicle. Due to many different and varying factors, the range is difficult to calculate precisely. Therefore, the paper introduced an estimation method where nine different factors are considered, including driver’s driving style, status of on-board electric devices, wind speed, acceleration and deceleration, road link travel speed, road network topology, remaining battery energy, vehicle current location and road grade. The CPS will be focused on the road grade factor specifically. The proposed method was to save time and computing resources where range prediction is classified into two; rough range estimation and precise range estimation based on the remaining battery energy. The paper also includes a detailed process flow. Experimental results summarized that the proposed method can provide precise driving range prediction, reduce the amount of computing resources and at the same time providing convenience to travellers (Zhang et al., 2012).

In the paper, Simplified Electric Vehicle Power Train Models and Range Estimation, simplified EV power train models are developed for new and existing production EVs. The models are developed based on published vehicle parameters and range information for two EVs; the Tesla Roadster and Nissan Leaf. The models are compared with published manufacturer specifications for various drive cycle, for range under various driving conditions and driving routes. The simulated models are additionally validated against experimental test results for the Tesla Roadster and Nissan Leaf where the test route topography and terrain is modelled using a GPS-based smart-phone application and Google Earth. Excellent correlations are demonstrated between the manufacturer data, experimental results and the vehicle models. This study also includes the impacts of battery degradation over time and the EV's HVAC loads (Hayes et al., 2011).

The journal, Techniques for Estimating the Residual Range of an Electric Vehicle, presents an algorithm that has been developed to estimate the residual range of an EV. For example, simulations are done for the distance that can still be covered with the energy stored inside the battery. The algorithm takes into consideration the complex behaviour of electrochemical batteries, as well as the main issues related to users' different driving styles. This paper also discussed the experimental results obtained by applying the algorithm into several urban test trips done using two different types of EVs (Ceraolo et al., 2001).

2.5 Results and Precision of Current Techniques / Distance Estimators

Since today's conventional distance estimators are based on a ratio basis(distance to battery energy), it is not accurate and reliable to represent the many different types of driving conditions especially uphill travelling. This is because driving an electric vehicle on a straight road and uphill for the same distance will consume different amount of battery energy but the conventional estimators could not tell the difference between the both.

Comparing between distance estimation without road elevation(conventional method) and distance estimation with road elevation from the journal titled 'Impacts of Road Grade on Fuel Consumption and Carbon Dioxide Emissions Evidenced by Use of Advanced Navigation Systems', comparison of the measured fuel economy between a flat route and example hilly routes revealed that the vehicle fuel economy of the flat route is superior to that of the hilly routes by approximately 15% to 20% (Boriboonsomsin et al., 2010).

This proves that the percentage difference of energy consumption is much more significant for an uphill travelling. The actual energy consumption cited in the journal mentioned above is approximately 15% to 20% more than the conventional distance estimation and this proves that today's distance estimators are not accurate enough to predict the energy consumption of an electric vehicle. Therefore, a new improved method of estimation is required and this is the main purpose of developing the CPS.

2.6 Problem Statement - Common Problems Faced by EV users

2.6.1 Battery System Limitations

Many different types of EVs were designed with the aim of solving global pollution problems caused by the emissions from gasoline-powered ICE engines. These serious environmental issues promote the adoption of new-generation EVs for urban transportation. In the journal paper, 'Battery choice and management for new-generation electric vehicles', it addresses that one of the biggest weakest points of EVs is the battery system. Some of the major drawbacks that prevent the introduction of EVs into the consumer market are vehicle autonomy and, therefore, accurate detection of battery state of charge (SoC) together with battery expected life, i.e., battery state of health. The electric motorcycle may provide the most feasible opportunity among EVs but they are not suitable for everyone to use. Apart from the battery choice and management, the drive performance, safety, and cost issues are also essential to be taken into consideration. However, the battery system choice is still a crucial factor and thanks to an increasing emphasis on vehicle range and performance, the Lithium-ion battery may become a viable solution (Affanni et al., 2005).

2.6.2 Speed and Power

Not too long ago, there was a concern within the electric vehicle community where there is an opinion that an electric vehicle can never have the speed and power that an internal combustion engine(ICE) vehicle has. But as time passes by and the technology involves around electric vehicles for the past few decades have tremendously improved, this growing concern is a thing of the past. Of course, comparing both EVs and ICE vehicles in terms of maximum power, the ICE will still come out on top due to the efficiency and maturity of the ICE technology for the past few centuries while EV technology was only starting to mature in the past three to four decades. However, a commercial electric vehicle nowadays can produce a maximum power and speed of up to 215kW and 200km/h respectively which is the Tesla Roadster. On average, most common EVs have a top speed of 130-150km/h which is a very comfortable performance for a user to drive on a normal highway.

Table 2.3 shows some of the common electric vehicles that are available in the market and some of the common characteristics that they have. All the EVs listed in the table runs on lithium-ion battery packs to produce an accurate and compatible comparison between one to the other.

Table 2.3: Electric Vehicles running on Lithium-ion battery specifications

	Max speed km/h	Motor Power kW	Motor torque Nm	Vehicle Weight kg	Battery Weight kg	Vehicle to battery weight ratio
Proton Saga EV	130	52	198	1,148	151	7.60
Nissan Leaf	150	80	280	1,535	171	8.98
Mitsubishi i-MiEV	130	49	180	1,170	147	7.96
Tesla Roadster	200	215	370	1,235	449	2.75
BMW Mini E	153	150	220	1465	259	5.66
Ford Focus EV	135	92	245	1,674	295	5.67

2.6.3 Charging Time and Charging Stations

The introduction of electric vehicles into our everyday life should not change our habits, nor should it expose us to situations that may be potentially hazardous when we charge our vehicles.

The common battery capacity of an electric vehicle is approximately 20kWh, providing it with a driving distance or range of around 100 kilometres. Chargeable hybrid electric vehicles have battery capacity of approximately 3 to 5kWh, for a range of around 20 to 40 kilometres and usually running completely on battery power for lower driving speeds. For hybrid electric vehicles, it needs to be charged on an average of every 2 or 3 days.

For normal charging, the vehicle usually has a built-in battery charger in it. A charging cable is used to connect the vehicle to an electrical network of 120/240V AC current supply depending on different countries. For faster charging, car manufacturers usually have two solutions where by using the vehicle's built-in charger, designed to charge at higher current capacity from 3 to 43kW at 230V single-phase or by using a three-phase 400V AC supply using an external charger which converts it into DC current and charges the vehicle at 50kW.

Charging an electric vehicle is as simple as connecting a normal electrical appliance into an electric socket. However, to ensure the process takes place safely, the charging system must perform several safety functions and communicate with the electric vehicle during connection and while charging (Charging Station, 2012).

One of the main concerns of using an electric vehicle is the availability of charging stations when the user is running low on battery energy while half-way driving their EVs and the charging time concerned. If the users decided to charge their EVs at public charging stations, what is the duration that is required for them to wait until their EV is fully charged? Compared to refuelling an internal combustion engine(ICE) vehicle with fuel which only takes a few minutes, charging an electric vehicle can take from 20 minutes for fast charging up to 2-3 hours at a public charging station by the roadside. Table 2.4 will provide a good indication on the charging time needed for different types of power supply with different voltage and current ratings.

Table 2.4: Charging time needed for different types of power supply with different voltage and current ratings

Charging time	Power supply	Voltage	Max current
6–8 hours	Single phase - 3,3 kW	230 VAC	16 A
2–3 hours	Three phase - 10 kW	400 VAC	16 A
3–4 hours	Single phase - 7 kW	230 VAC	32 A
1–2 hours	Three phase - 24 kW	400 VAC	32 A
20–30 minutes	Three phase - 43 kW	400 VAC	63 A
20–30 minutes	Direct current - 50 kW	400 - 500 VDC	100 - 125 A

Developed countries like the United States are having more and more charging stations around their country and some of the available ones are in California, Texas and San Francisco.

Figure 2.2: **Andromeda Power ORCA Mobile charger: the only 50,000 Watt mobile charger, Anaheim, California, USA (Charging Station, 2012).**

Figure 2.3: **Nissan Leaf recharging from a NRG Energy eVgo station in Houston, Texas (Charging Station, 2012).**

Figure 2.4: Public charging stations in San Francisco (Charging Station, 2012).

However, developing countries such as Malaysia are still at an infant stage when it comes to electric vehicles and charging stations are not available at the moment. The government has plans to introduce the first electric car from Proton in the year 2013 and charging stations are most likely available in cities such as Putrajaya and Cyberjaya. Therefore, for electric vehicles to be widely available in developing countries such as Malaysia, there is a need to produce more charging stations around the major cities in the country in the near future.

2.6.4 Range Anxiety

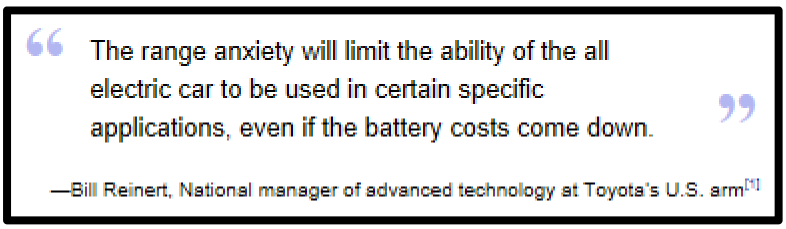
Range anxiety is the fear that a vehicle has insufficient range to reach its destination and would thus strand the vehicle's occupants in the middle of a road. Many electric designs have limited range, due to the low energy density of batteries compared to the fuel of internal combustion engine vehicles. Electric vehicles also often have long recharge times compared to the relatively fast process of refuelling a tank. This is further complicated by the current scarcity of public charging stations. "Range anxiety" is a label for consumer concern about EV range.

The term, which is mainly referred to battery electric vehicles (BEVs), is one of the major problems to a large scale adoption of fully electric cars. The concern that many users of electric vehicles have is getting stranded somewhere in the middle of the road due to insufficient battery energy or capacity leads to calls for more public charging stations throughout the country. In response, electric vehicle manufacturers have sought to quell the concerns through increased battery capacities to extend the vehicle's range. For example, through a proprietary technology where a battery reserve can be released by texting or calling an operation centre, by using a range extender solution, as done in the Chevrolet Volt, or through a proposed modular vehicle approach where a vehicle's chassis can be inserted with a larger capacity battery before leaving on a long distance journey. The term ‘range anxiety’ was first reported on September 1, 1997 in the press, San Diego Business Journal by Richard Acello where he helped to voice the GM EV1 electric car drivers worries. Fast forward many years later, US automotive giant General Motors filed to trade mark the term on July 6, 2010, with the purpose of "promoting public awareness of electric vehicle capabilities".

Since this understanding can be due to a lack of information, an accurate navigation system with knowledge of the battery capacity and precise estimation of the remaining distance can minimize the fear and solve this problem. This can also alleviate the fear and promote confidence to potential buyers of an electric vehicle.

The American Automobile Association (AAA) has also worked on providing a solution to this problem in six cities in the US where AAA members using electric vehicles can recharge their vehicles up to 80% capacity within 30 minutes.

To summarize it all, the fear of ‘range anxiety’ can be similarly illustrated as the human body having inadequate stamina, as well as inadequate speed to get to a desired destination; similar to the major barrier faced by electric vehicles. (Range Anxiety, 2012).


“The range anxiety will limit the ability of the all electric car to be used in certain specific applications, even if the battery costs come down.”

—Bill Reinert, National manager of advanced technology at Toyota's U.S. arm[1]

Figure 2.5: Bill Reinert quote on electric car’s range (Range Anxiety, 2012)

2.7 Problem Statement - Variables That Affect Inaccuracy of Current Distance Estimation Systems

2.7.1 Elevation

Recently, advanced navigation systems have been developed that provide users the ability to select not only a shortest-distance route and even the shortest-duration route (on the basis of real-time traffic congestion information) but also routes that minimize fuel consumption as well as greenhouse gas and pollutant emissions. In these Eco routing systems, fuel consumption and emission attributes are estimated for roadway links on the basis of the measured traffic volume, density, and average speed. Instead of standard travel time or distance attributes, these link attributes are then used as cost factors when an optimal route for any particular trip is selected. In addition to roadway congestion attributes, road grade factors also have an effect on fuel consumption and emissions.

A study was done to evaluate the effect of road grade on vehicle fuel consumption (and thus carbon dioxide [CO_2] emissions). The real-world experimental results show that road grade does have significant effects on the fuel economy of light-duty vehicles both at the roadway link level and at the route level. Comparison of the measured fuel economy between a flat route and example hilly routes revealed that the vehicle fuel economy of the flat route is superior to that of the hilly routes by approximately 15% to 20%. This road grade effect will certainly play a significant role in advanced Eco routing navigation algorithms, in which the systems can guide drivers away from steep roadways to achieve better fuel economy and reduce CO_2 emissions (Boriboonsomsin et al., 2010).

2.8 Current SOC and Distance Estimation Techniques, Methods Used and Their Results

An accurate battery State of Charge estimation is of great significance for battery electric vehicles and hybrid electric vehicles. A journal, ‘Adaptive unscented Kalman filtering for state of charge estimation of a lithium-ion battery for electric vehicles’, from Elsevier published in April 2011 presents an adaptive unscented Kalman filtering method to estimate State of Charge of a lithium-ion battery for battery electric vehicles. The adaptive adjustment of the noise covariances in the State of Charge estimation process is implemented by an idea of covariance matching in the unscented Kalman filter context. Experimental results from this journal indicate that the adaptive unscented Kalman filter-based algorithm has a good performance in estimating the battery State of Charge. A comparison with the adaptive extended Kalman filter, extended Kalman filter, and unscented Kalman filter-based algorithms shows that the proposed State of Charge estimation method has a better accuracy (Sun et al., 2011).

2.8.1 Battery Management System and State-of-Charge Development for EVs

Battery monitoring is an important factor for all EVs because the safety, operation, stability, and even the life of the passenger depend on the battery system. This attribute is the major function of the battery management system (BMS) where one of its main tasks is to check and control the status of battery within their specified safe operating conditions. In the paper, Battery-Management System (BMS) and SOC Development for Electrical Vehicles, a typical BMS block diagram has been proposed using various functional blocks. The state of charge (SOC) estimation has been implemented using Coulomb counting and open-circuit voltage methods where it eliminates the limitation of the stand-alone Coulomb counting method. By modelling the battery with SOC as one of the state variables, the SOC can be estimated and further corrected by the Kalman filtering method. The battery parameters from experimental test results are integrated into the model and simulation results are validated by experiment (Cheng et al., 2011).

2.8.2 A MATLAB Based Modelling and Simulation for EV Design

This journal, ‘A MATLAB-Based Modeling and Simulation Package for Electric and Hybrid Electric Vehicle Design’ discussed a modelling package and simulation developed at the Texas A&M University. V-Elph 2.01 facilitates in-depth studies of EV configurations or energy management strategies through visual programming by creating components as hierarchical subsystems that can be used interchangeably as embedded systems. V-Elph is composed of detailed models of four major types of components in a vehicle; internal combustion engines, batteries, electric motors, and support components that can be integrated to model and simulate drive trains having all electric configurations. V-Elph was written in the MATLAB/Simulink graphical simulation language and is functional on most computer platforms.

This paper also discussed the methodology for designing vehicle drive trains using the V-Elph package. An EV driven drive train have been designed using the simulation package. Simulation results such as vehicle emissions, complexity, and fuel consumption are all compared and discussed in this paper for an EV (Butler et al., 1999).

2.8.3 Techniques for Predicting the Residual Range of an EV

The journal, ‘Techniques for Estimating the Residual Range of an Electric Vehicle’, presents an algorithm that has been developed to estimate the residual range of an EV, For example, simulations are done to discover the distance that can still be covered with the remaining energy stored inside the battery pack. The algorithm takes into consideration the complex behaviour of electrochemical batteries as well as the main issues related to different user’s driving styles. This paper also discussed the experimental results obtained by applying the algorithm into several urban test trips done using two different types of EVs (Ceraolo et al., 2001).

2.8.4 Remaining Driving Range Prediction of EVs

As discussed in Chapter 2.4 regarding the current techniques and method used in distance estimators, this paper recognises the importance of distance estimations for the remaining driving range of an electric vehicle and therefore came out with a proposed method to provide an accurate and precise driving range estimation by considering nine different factors. At the same time, this solution also reduces the amount of computing resource and provides convenience to travellers (Zhang et al., 2012).

2.8.5 Simplified EV Power Train Models and Range Prediction

In the paper, Simplified Electric Vehicle Power Train Models and Range Estimation, simplified EV power train models are developed for new and existing production EVs. The models are developed based on published vehicle parameters and range information for two EVs; the Tesla Roadster and Nissan Leaf. The models are compared with published manufacturer specifications for various drive cycle, for range under various driving conditions and driving routes. The simulated models are additionally validated against experimental test results for both the EVs where the test route topography and terrain is modelled using a GPS-based smart-phone application and Google Earth. Excellent correlations are demonstrated between the manufacturer data, experimental results and the vehicle models. This study also includes the impacts of battery degradation over time and the EV's HVAC loads (Hayes et al., 2011).

2.8.6 Smartphone based Software for Range and Energy Efficient Route Selection for EVs

The term ‘Range anxiety’, is the fear of running out of energy and battery power while driving on the road is one of the major barriers to large scale adoption of electric vehicles. Range prediction methods and solutions are available to address this anxiety but most of them have limited functionalities and flaws. In this research, the authors proposed an “Accurate Range” and “Energy-efficient Route” (ARER) selection mobile software solution which is based on a smartphone platform. The proposed solution provides numerous attractive features.

The main feature is estimation of the most accurate driving range by taking into consideration real time factors that were never considered in the prior art such as geographical terrain of the driving route like elevation and depression, real time alert implemented on the road, for example, the road flood clogged or blocked due to catastrophe or natural disasters, a new public safety system that will enable government officials to send emergency text alerts such as terrorisms, floods, and tornados to specific affected geographic areas through cell towers, real-time wind speed, real-time weight on the vehicle, and real time traffic conditions, comparing with and feedback into the available battery energy.

The second feature that leverages on the earlier proposed solution is proposing alternative routes that may be longer but more energy efficient, for example, the route with depression instead of elevation, not flood, clogged or blocked, the route with favourable wind directions at that instant and location, the route with lesser traffic jams and congestions, fewer junctions, stop signs, traffic light etc.

The third feature is to evaluate the service relevance and suggest the point of service that offers similar services that fall on the most energy efficient route. For example, if the electric vehicle driver searches for Guardian or Watson pharmacies, the software may also suggest Tesco, Aeon, or Cold Storage because of the service relevance or similar service offerings and occurrence on the most energy efficient route from the driver's current location.

The fourth feature is where the software keeps the history of the roads traversed, route travelled and uses the log data for future optimizations.

The fifth and final feature is where the software produces a visual 360-degree real time range display, and then calculates the estimated energy cost of driving a chosen route. (Yaqub et al., 2012).

2.8.7 Range Prediction for Nissan Leaf and Tesla Roadster using Simplified Power Train Models

In this paper, 'Range Estimation for the Nissan Leaf and Tesla Roadster using Simplified Power Train Models', the research done by the authors are almost similar to the paper published, 'Simplified Electric Vehicle Power Train Models and Range Estimation' in Chapter 2.8.5. The major difference was this paper is more focused on two specific EVs; the Nissan Leaf and Tesla Roadster. Simplified EV power train models are also used to simulate and estimate the range for both the EVs and the models are compared with published manufacturer specifications. Other studies are also done such as impacts of vehicle HVAC loads and battery degradation over time on the EVs. (Oliveira et al., 2011).

2.8.8 User Driving Pattern Identification for EV Range Prediction

This paper, 'Driving Pattern Identification for EV Range Estimation' proposed a driving pattern recognition solution based on trip segment clustering. Driving patterns categorize various driving behaviours that contain certain energy demand property in common. It can be applied to various applications including emission estimation, energy management controls, intelligent transportation, and passive/active safety controls. The pattern features are first identified through high impact factors from traffic information and static and quasi-static environmental. A feature based trip or route partitioning algorithm will be developed based on data clustering methods. Finally, the driving patterns are recognized by synthesizing all the partitioned feature zones along the trip or route where each partitioned road section is distinguished by an attribute of feature combination that will result in a distinctive drive energy demand property. To summarize, this driving pattern recognition is an essential technology specifically in problem solving solutions such as range prediction and energy consumption pre-planning for the fully powered battery EVs (Hai et al., 2012).

2.8.9 Using Advanced Navigation Systems to Determine Impacts of Road Grade on Fuel Consumption

Recently, advanced navigation systems have been developed that provide users the ability to select not only a shortest-distance route and even the shortest-duration route (on the basis of real-time traffic congestion information) but also routes that minimize fuel consumption as well as greenhouse gas and pollutant emissions. In these eco-routing systems, fuel consumption and emission attributes are estimated for roadway links on the basis of the measured traffic volume, density, and average speed. Instead of standard travel time or distance attributes, these link attributes are then used as cost factors when an optimal route for any particular trip is selected. In addition to roadway congestion attributes, road grade factors also have an effect on fuel consumption and emissions. This study evaluated the effect of road grade on vehicle fuel consumption (and thus carbon dioxide [CO_2] emissions). The real world experimental results show that road grade does have significant effects on the fuel economy of light-duty vehicles both at the roadway link level and at the route level. Comparison of the measured fuel economy between a flat route and example hilly routes revealed that the vehicle fuel economy of the flat route is superior to that of the hilly routes by approximately 15% to 20%. This road grade effect will certainly play a significant role in advanced eco-routing navigation algorithms, in which the systems can guide drivers away from steep roadways to achieve better fuel economy and reduce CO_2 emissions (Boriboonsomsin et al., 2010).

2.9 Data Accuracy of Google Earth Elevation Database

The data accuracy of Google Earth elevation database is measured by the elevation resolution. One of the main source Google Earth uses digital elevation model(DEM) data is collected by NASA's Shuttle Radar Topography Mission (SRTM) (Farr et al., 2007). Apart from that, as with much of their geo data, Google obtain data from many different providers (over 100 for elevation alone) which they stitch together to provide the best possible level of coverage. At the moment, to provide information on the accuracy of the data available on Google Earth’s elevation database, Google would have to provide source information per request, which is a lot of engineering for little gain. The main reason most developers are asking for source information appears to be because they want to know the resolution. This being the case Google will be looking into providing resolution information in elevation responses in the future (Google Maps, 2010).

2.10 Navigation Efficiency and Error Estimation of the GPS-based Navigation System

Since the CPS navigates direction based on the Global Positioning System (GPS), the reliability and navigation efficiency is largely dependent on it. The GPS is a satellite-based navigation system made up of a network of 24 satellites placed into orbit by the U.S. Department of Defence. A GPS receiver must be locked on to the signal of at least three satellites to calculate a 2D position (latitude and longitude) and track movement. With four or more satellites in view, the receiver can determine the user's 3D position (latitude, longitude and altitude). Today's GPS receivers are extremely accurate, thanks to their parallel multi-channel design. Most standard GPS receivers are accurate to within 15 meters on average. Newer GPS receivers with WAAS (Wide Area Augmentation System) capability can improve accuracy to less than three meters on average. Users can also get better accuracy with Differential GPS (DGPS), which corrects GPS signals to within an average of three to five meters. Only certain atmospheric factors and other sources of error such as ionosphere and troposphere delays and signal multipath can affect the accuracy of GPS receivers (Garmin, 2012).

A research was also conducted by Prof. Jacek Czajewski on the actual accuracy of GPS and Differential Global Positioning System(DGPS) where the author carried out the first observations of the GPS Precise Positioning Service(PPS) accuracy just two weeks after PPS was made available to civil users. The experiments were conducted with a Geonav LCD11 and a computerized GPS receiver equipped with electronic charts manufactured by Navionics, an Italy based company. Tests conducted during stopovers at harbours outside DGPS range, Tromso in Norway and Longyearbyen, Ny-Alesund on Spitsbergen, proved maximum errors (converted to meters) in the range of $\Delta\phi = \pm 4.7\text{-}10.2$m for latitude and $\Delta\lambda = \pm 3.0\text{-}11.5$m for longitude. Measurements made with DGPS in Wilhelmshaven showed that the maximum inaccuracy is $\Delta\phi = \pm 3.7$m, $\Delta\lambda = \pm 4.8$m. Subsequent tests in other havens and using other receivers provides the confirmation for these results.

Since there was no possibility of automatic calculation of the mean value of longitude and latitude, a series of positions acquired during several (up to a few dozen) hours was recorded, as points on the electronic chart for the error estimation. They formed a typical Gaussian distribution as they were symmetrically distributed around a central point. The farther the distribution is from that point, the sparser the distribution and no points outside of a clearly marked outline. Thus, maximum longitude and latitude differences in this area were determined. Assuming that the real position falls in the centre of the area, the error, with the ± sign, was defined as half of these differences converted to meters (Michalski et al., 2004).

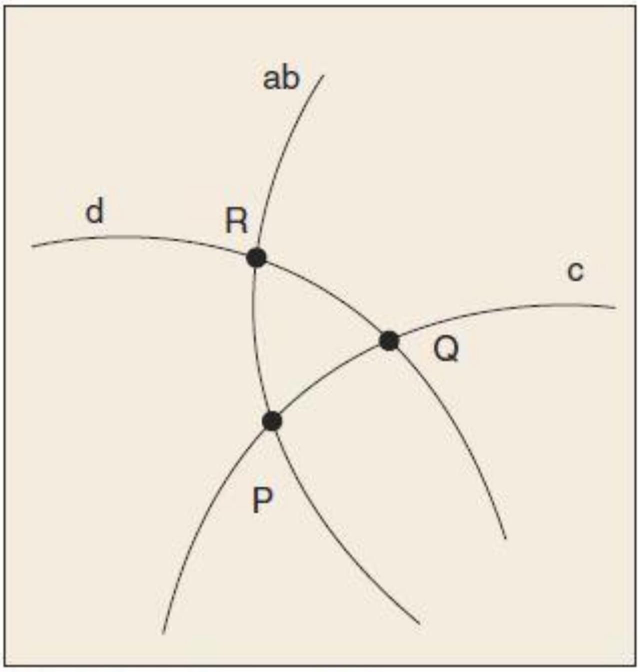


Figure 2.6: GPS Triangle of Error (Michalski et al., 2004)

2.11 Real-world Experimental Testing on the Honda Civic Hybrid

To test the range prediction systems in a real electric vehicle, a real world experimental testing was done on the latest Honda Civic Hybrid that was launched in early 2012. The Honda Civic Hybrid was selected because it has an electrical drivetrain in it and it is the closest representation of an electric vehicle here in Malaysia at the moment.

For the drive test, the Honda Civic Hybrid was tested on two different road conditions, a normal road terrain with minimal slopes and bumps and a road condition with hilly and bumpy terrains. After driving the vehicle on the two road conditions for several minutes, the estimated driving range was simulated by the vehicle's system and a conclusion was made.

After the testing were done, it was observed that the Honda Civic Hybrid has a self-learning algorithm that predicts the estimated driving range after the vehicle has been moving and drove around for the first few minutes. From this observation, the algorithm will generate different results for different driving and road conditions. For example, after driving 5 minutes on a straight road, the energy consumption from the battery pack was 5% and therefore, the estimated driving range was 100 minutes. The other example was driving on a hilly road for 5 minutes, the energy consumption from the battery pack was 10% and therefore, the estimated driving range predicted by the algorithm was 50 minutes.

This was just a rough test done on a new electric vehicle that is available in the market to have a feel of how the current range prediction method was executed to estimate the amount of distance that can be travelled by that vehicle and therefore, no accurate data was recorded.

From these results and observation, it was concluded that the driving energy consumption for the first few minutes are extrapolated to determine the total driving range of the vehicle. This shows that there are no accurate methods to estimate a driving distance for the Honda Civic Hybrid and the extra energy consumed due to different road elevations are not taken into account.

2.12 Literature Review Summary

To summarize, this research title was proposed starting from the problems that current users have with the use of electric vehicles where the term, 'Range Anxiety' is a well-known issue that has been a major problem for the commercialization of real EVs on the road. It was always a matter of battery pack capacity versus the distance travelled that can be covered by an electric vehicle. A global study was also done by Accenture in 2011 where 85% of users claimed EVs have insufficient battery range to cover their daily driving needs. One of the main reasons why this problem is worth solving is because running out of electricity isn't the same as running out of gas. No one can come to your aid with a gallon of electricity to tide you over if you are stranded right in the middle of the road (Accenture, 2011).

From the problems mentioned above, it would be viable to conduct a thorough research on one of the main factors that affects the inaccuracy of the current range prediction methods. In a research that was published in a journal titled, "Impacts of Road Grade on Fuel Consumption and Carbon Dioxide Emissions Evidenced by Use of Advanced Navigation Systems" by the Transportation Research Record: Journal of the Transportation Research Board, the research produced real-world experimental results that proves that road grade does have significant effects on the fuel economy of light-duty vehicles. At the end of this journal, it was concluded that comparison of the measured fuel economy between a flat route and hilly routes revealed that the vehicle fuel economy of the flat route is superior to that of the hilly routes by approximately 15% to 20% (Boriboonsomsin et al., 2010).

In the book titled, "Electric Vehicle Technology Explained", the significance and importance of extra power and energy needed by an electric vehicle to climb hills is also highlighted. It mentioned that it is taking heavy vehicles up hills that require high power. Considerable power is required for hill climbing, and such terrain will restrict the range of electric vehicles relying solely on rechargeable batteries. It was also emphasized that when designing electric vehicles, the effect of hills must be taken into account, though they are no agreed 'standard hills' for doing this. At the same time, this consideration is also usually done with a specific journey in mind (Larminie et al., 2003).

From the research results published in the journal and book mentioned above, it is proven that the effects of road slopes as one of the main factors that affects the inaccuracy of the current range prediction methods is a viable research methodology that can be focused on. A thorough and in-depth research can be executed to improve on the current range prediction methods that are currently available for electric vehicles in the market. This is the main objective of the research on developing the Contour Positioning System(CPS) where a novel range prediction technique in electric vehicles will be researched on using certain programming methods and real-world result simulations.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction to the Research Method of the Contour Positioning System

The Contour Positioning System is a new, more accurate and precise distance estimation system or range prediction method for electric vehicles to reach from one destination to the other destination safely without running out of battery energy and stranding in the middle of a road. The novelty of this research is that it includes elevation and slope information into its distance estimation calculation and simulations which has been proven in published journals where this factor alone will consume approximately 15% to 20% additional battery energy (Boriboonsomsin et al., 2010). Therefore, a method is needed to be developed and a research in this area needed to be done to solve this problem.

Before the introduction of software to calculate and simulate the results for distance estimation in an electric vehicle, all the research calculation and simulations for the CPS was done using an Excel spread sheet with formulas inserted into the function bar to tabulate simulated results. The information and data extraction method was also done manually where by the mouse is moved over each point by point in the Google Earth's elevation profile to obtain the distance and elevation information and all these data will be recorded into the Excel spread sheet manually for the calculation and simulations later on.

Using this method to calculate and simulate the distance estimation results for the CPS consumes a lot of time and only a limited numbers of data can be obtained. This is because to just record down 5km of distance and elevation information from Google Earth into the Excel spread sheet already take approximately 3 to 4 hours if this method is done manually by moving the mouse over to every point in the 5km distance in the Google Earth's elevation profile. Therefore, this manual method will not be possible to calculate and simulate results for longer distances such as 10km, 50km or even 100km because it will take too much time.

Moreover, the information and data obtained from Google Earth's elevation profile will not be accurate because the accuracy is depending on what the mouse's cursor can move over on the screen and that is the only distance and elevation results that one can obtain. In addition to that, a distance point in the elevation profile can generate multiple elevation and slope angle information when the mouse's cursor moves over two or three closely positioned points in the elevation profile.

In Figure 3.1, the snapshot provided shows a distance point of 27km in Google Earth's elevation profile can produce three different elevation positions of 904m, 908m and 915m and also three different slope angles of 13.4%, 11.0% and 9.2%. Therefore, this will result in inaccuracy of the data and information obtained and will affect the calculation and simulations of results later onwards. To solve this problem, a new method of research needed to be developed instead of obtaining the data and information manually from the elevation profile.

Figure 3.1: The same distance in Google Earth Elevation Profile producing three different elevations and slope angles

Recognising all these as problems to developed an effective distance estimation research method for the CPS, a need for an automatic data extraction and simulation software are necessary to produce accurate distance estimation results. Therefore during the early stage of the CPS research, a few software to carry out the tasks mentioned above was recommended such as Python programming, Microsoft Access, Mathematica, C++ programming, MATLAB programming, Advanced Vehicle Simulator(ADVISOR) etc. ADVISOR is an Advanced Vehicle Simulator that simulates the performance of hybrid electric, conventional, electric, and fuel cell vehicles. The software was created by the U.S. Department of Energy's (DOE) Office of

Transportation Technologies' (OTT) Hybrid Vehicle Program. ADVISOR calculates the fuel economy, emissions released, acceleration times, and much more for a given drive cycle (Markel et al., 2002).

After careful consideration and research on the functions and capability of all the software proposed, in the end, Python and MATLAB programming was considered due to many positive factors. All these factors and the choice of selecting Python and MATLAB to perform the functions needed for distance estimation in the CPS will be discussed further and in more details in the following chapters. The following chapters in the Research Methodology will discuss in detail on the information and data utilized in the CPS, different methods and algorithms used in the CPS, the uniqueness/ speciality of the CPS, innovation/novelty of the CPS and many more.

3.2 Introduction to MATLAB Programming

MATLAB® is a high-level language and interactive environment for numerical computation, visualization, and programming. Using MATLAB, you can analyze data, develop algorithms, and create models and applications. The language, tools, and built-in math functions enable you to explore multiple approaches and reach a solution faster than with spreadsheets or traditional programming languages, such as C/C++ or Java™.

MATLAB can be used for a range of applications, including signal processing and communications, image and video processing, control systems, test and measurement, computational finance, and computational biology. More than a million engineers and scientists in industry and academia use MATLAB, the language of technical computing (MATLAB, 2012).

The main reason why MATLAB was chosen for the implementation of this research was its ability to operate together with the Python programming. Python programming will extract the distance and elevation information from Google Earth’s elevation profile and stores them into an Excel spread sheet. All these data and information stored in the Excel file needs to be compatible and utilized by the MATLAB programming thereafter. Furthermore, MATLAB programming is widely used by engineers and scientist worldwide, therefore the availability of its programming codings and step-by-step tutorials are easily accessible from the internet.

3.3 Information and Data Utilized in Contour Positioning System

The information and data utilized are from Google Earth, specifically from the elevation profile details in the mapping. There are many information available from the elevation profile such as coordinates of every point in the path or distance selected and those coordinates can be shown in either decimals or degrees, minutes, seconds in the Google Earth options. Other information are also available such as the distance for the two selected coordinates in meters, elevation(in meters) with respect to sea level for every coordinate in the selected distance, slope angles in percentage, total distance and range in kilometres etc. An example of a Google Earth elevation profile is shown in Figure 3.2:

Figure 3.2: An Example of Google Earth's Elevation Profile

Other information and data that are used in the CPS are the general electric vehicle's technical data and specifications. Some of the parameters used in the MATLAB programming and simulations are the vehicle's electric range in kilometres, climbing ability in percentage, motor power in kW, battery energy in kWh etc.

3.4 Different Methods and Algorithms Used in Contour Positioning System

Before this research was started, many programming and simulation software were considered to be used for the CPS such as C++ programming, Mathematica and MATLAB. After a thorough research on the functions and capability of all the software that was proposed, MATLAB programming was selected because of the convenience of utilizing the data and information extracted from the Google Earth elevation profile and stored into an Excel spread sheet by the Python programming software.

The data and information that was utilized from the Excel spread sheet by the MATLAB programming are the distance and elevation information that was extracted by Python programming from Google Earth elevation profile into the Excel spreed sheet. In simple terms, the Python programming extracts distance and elevation data from Google Earth and stores them into an Excel spread sheet, and then MATLAB programming will utilize all the distance and elevation information from that same Excel spread sheet for calculations and simulations of distance estimation results in the CPS. An example of the MATLAB programming coding that utilizes the data and information stored in an Excel spread sheet is shown in Figure 3.3:

```
close all;
clear all;
clc;
fname='CPS.xls';
[txt,data,all]=xlsread(fname,1);
%disp(txt(7:10,1));
```

Figure 3.3: MATLAB programming that utilizes data and information stored in an Excel spread sheet

From the diagram above, it is obvious that it is simple and convenient to obtain and utilize the information and data that are stored in an Excel spread sheet. From the programming above, the file name is CPS.xls which is the excel file that stores the distance and elevation data from Google Earth elevation profile. The *'[txt,data,all]=xlsread(fname,1);'* coding will extract text, data and all the other information stored in the CPS.xls Excel file. *‘xlsread’* is the MATLAB function that will carry out the extraction tasks, and *‘(fname,1)’* is the function that will enable *‘xlsread’* to extract data and information from the first spread sheet in the CPS.xls Excel file.

3.5 Uniqueness/Speciality of the CPS

The uniqueness that the research on the CPS has is that it can be customized to be implemented onto typically any electric vehicle as long as the vehicle’s specifications and technical data are available. All that is needed to be tested onto another electric vehicle is to change the parameters of the EV specifications in the MATLAB programming. Moreover, this research and development of the CPS is very low cost because almost all of the applications and functionality in the system are software based.

The basic understanding of the CPS is where it is a new research area invented for electric vehicles(EV) to calculate the remaining battery capacity and provides accurate estimation of the amount of battery energy needed(%) for the user to drive to a desired destination using information and data obtained from elevation profiles.

This research is also unique because none of the research area on electric vehicles in patents and journals has taken account of information and data from elevation profiles into a distance estimation calculation and simulations for electric vehicles. To prove this point, a patent(PI 2012002380) has already been filed for this innovation means it is not available anywhere else.

3.6 Innovation/Novelty of the CPS

The most innovative point of the CPS is that it uses information and data from elevation profile to accurately estimate the distance and amount of battery energy needed(%) for the user to drive an electric car to a desired destination. It is important to use elevation profiles to estimate the distance and battery capacity because a car moving on roads with different slope angles will definitely consume different amount of energy from the battery pack. For example, driving up a hill for 100km in a 10% slope uses a lot more battery energy compared to driving 100km on a normal 0% straight road highway. As long as the specifications and technical data such as motor power and torque, battery voltage and energy(kWh), energy density(Wh/kg), climbing ability and etc are available and obtainable from the car manufactures, research on the CPS can be tested onto any electric car.

For the proof of concept, the CPS has already produced a patent, one journal, and three paper publications. The originality of concept is proven with the patent filing which means no one else had filed this concept anywhere in the world. The outstanding feature and functionality of the CPS is that it uses elevation profile and road slope angles to estimate the current and energy needed for an electric car to travel to a desired destination. This innovation is important because it makes the distance and battery capacity estimations accurate and reliable. Electric car users will never need to worry about 'range anxiety' anymore or fear of stranded halfway by the roadside due to inaccurate distance estimation systems.

3.7 New Proposed CPS Research

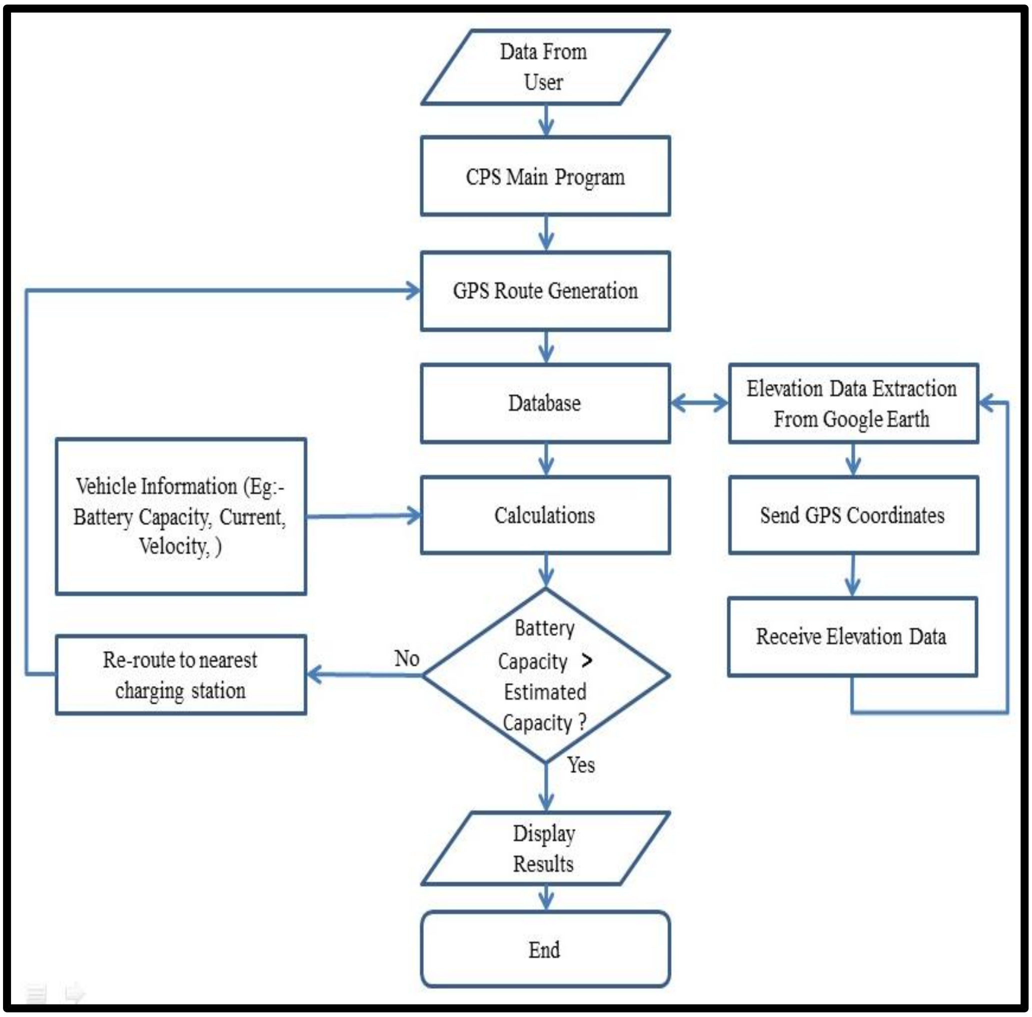


Figure 3.4: Block diagram function of the CPS

Figure 3.4 shows the block diagram function of the CPS and all the important functions and flow that are needed to be included into the program simulations. The CPS will be integrated as part of a system software in the

EVICS. To use the CPS in an electric car, the user must first determine and select the desired destination. This is the information that is needed from the user. Assuming the EVICS has an internet connection using a wireless USB WiFi adapter, the CPS will detect and pre-calculate the electric car's current position in Google Earth and draws the path to the desired destination. In the experiment conducted, the path drawn is from Berinchang(4°29'30.16"N 101°23'15.65"E, elevation 1497m) to Equatorial Hotel(4°30'17.64"N 101°24'31.18"E, elevation 1629m) in Cameron Highlands, Malaysia. From here, the CPS will extract the distance, elevation height and measured slope percentage data from Google Earth's elevation profile and calculates them according to the steps from (1) to (7).

All these data acquisitions and calculations have to be acquired in real-time and will be simulated in the background of the CPS software using a set of programming algorithms. The data extraction and acquisitions are performed by using Python programming and all the data and information will be stored into an Excel spread sheet. All the data from that Excel file will be used for calculation and simulation of results where this whole process will then be executed using MATLAB. Since the EVICS is built based on a multiple processor platform, the results will be simulated within a few seconds. Finally, the CPS will execute and display the amount of energy(Wh) and battery capacity(%) needed for the user to drive to the desired destination. If the amount of energy is not enough, the CPS will advise the user to drive to the nearest charging station.

3.8 Data Utilization and Calculations

After the Python programming extracts all the necessary data and information such as distance and elevation from the Google Earth's elevation profile and stores them into an Excel spread sheet, all these information will be utilized by the MATLAB programming for range prediction results and distance estimation simulations. To compute the results and simulations, numerous engineering and mathematical equations are utilized in the calculations process.

The calculation process in MATLAB is started by computing the distance difference between two corresponding coordinates stored in the Excel spread sheet. This Excel spread sheet stores the distance and elevation information extracted by the Python programming from the Google Earth's elevation profile. An example of the distance and elevation information stored in the Excel spread sheet is shown in Figure 3.5:

	A	B	C	D	E	F
1		Output Data:				
2		xx				
3		yd-500				
4		5000500x160x1				
5		-500				
6	[0	5000d%3A1495.94335938				
7	10	1496.44775391				
8	20	1496.95666504				
9	30	1497.47021484				
10	40	1497.98815918				
11	50	1498.51062012				
12	60	1499.03771973				
13	70	1499.56933594				
14	80	1500.10546875				
15	90	1500.54870605				
16	100	1500.97753906				
506	5000	1622.68151855				
507	5010	1623.23217773				
508	5020	1623.78271484				
509	5030	1624.33325195				
510	5040	1624.88391113				
511	5050	1625.43444824				
512	5060	1625.98510742				
513	5070	1626.53564453				
514	5080	1627.02502441				
515	5090	1627.03759766				
516	5100					
517	5110					
518	5120					
519	5130					

Figure 3.5: An example of the distance and elevation information stored in the Excel spread sheet

The calculation is first conducted by selecting a point to point direction in Google Earth. In this simulation, Berinchang to Equatorial Hotel Cameron Highlands have been selected where the driving distance is mostly uphill as shown in Figure 3.6.

Figure 3.6 also shows how the elevation profile was produced to collect the distance and elevation height data for every point. Samples of data were collected for every 10m of distance interval.

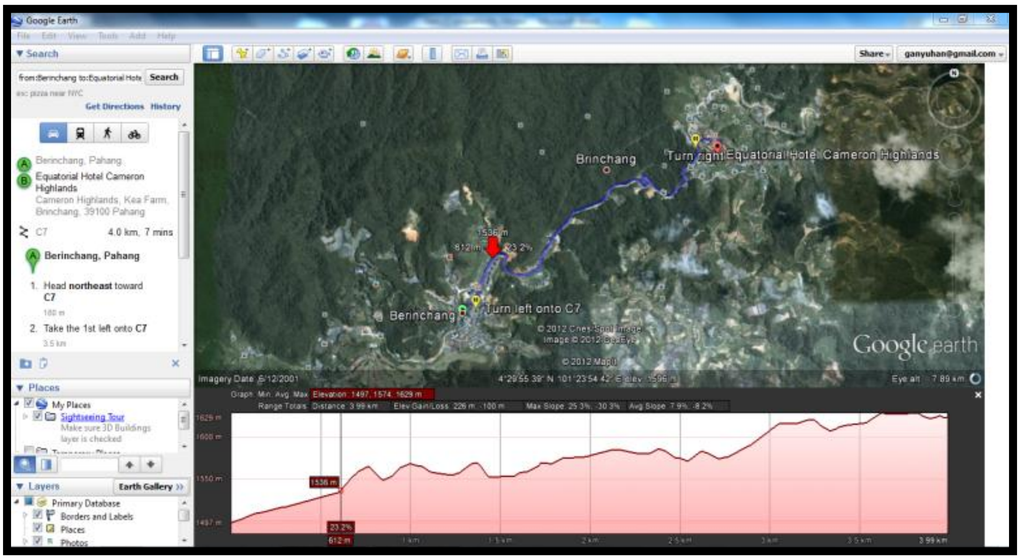


Figure 3.6: Google Earth Elevation Profile from Berinchang to Equatorial Hotel Cameron Highlands

Specifications	Saga EV	Saga 1.6AT
VEHICLE PERFORMANCE		
Type	Pure Electric	ICE (Petrol)
Vehicle Type	5 Seater Sedan	5 Seater Sedan
Kerb Weight (kg)	1,148	1,065
Fuel Consumption (l/100km) (ECE R101)	0	6.3
CO_2 Emission (g/km) (Tailpipe)	0	160
Electric Range (km) (*Target)	≥ 120*	-
Acceleration (0–100km/h) (s) (*Target)	≤ 10*	14.0
Top speed (km/h) (*Target)	130	165
Climbing Ability (%)	25	20
MOTOR & BATTERY		
Motor Type	Permanent Magnet AC Synchronous	-
Motor Power	52 kW	-
Motor Torque	198 Nm	-
Battery Type	Lithium Ion	-
Battery Energy (Peak)	15.9 kWh	-
Energy Density	105 Wh/kg	-

Figure 3.7: Proton Saga EV Specifications (Zainuddin, 2011)

Figure 3.7 above shows the Proton Saga EV specifications from the vehicle's performance to some of the motor and battery characteristics. Some of the specifications will be useful in the CPS simulations and to compare both the distance estimation method's performances such as electric range, climbing ability and the peak battery energy.

After all the data have been collected, each sample has a distance and elevation height and will be stored in an Excel spread sheet. From here, the distance difference and elevation height difference were calculated as below:

Distance Difference(m)= Distance–Previous Distance (1)

$$\Delta d = d_i - d_{i-1}$$

Elevation Difference(m)= Elevation–Previous Elevation (2)

$$\Delta e = e_j - e_{j-1}$$

The slope angles for both degree and percentage were also calculated to be compared to the measured slope angle obtained from Google Earth using the mathematical trigonometry Law of Sines function for a right angle(90º) triangle. The relationship and calculations between slope angle, distance and elevation difference are shown in Figure 3.8:

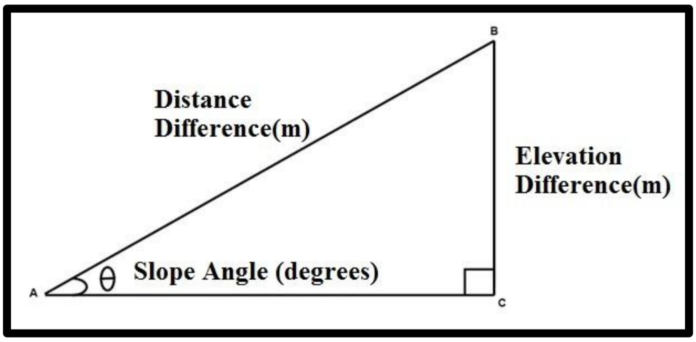


Figure 3.8: Relationship between slope angle, distance and elevation difference

$$\theta = \arcsin \frac{\text{Elevation Difference}}{\text{Distance Difference}}$$

$$\theta = \arcsin \frac{|\text{Elevation Difference}|}{\text{Distance Difference}}$$

the modulus or absolute value is included into the Elevation Difference because it may return either a positive or negative value but an *arcsin* function can only calculate a positive value problem

$$\angle(\theta) = \frac{|\text{Elevation Difference}|}{\text{Elevation Difference}} \times \arcsin \frac{|\text{Elevation Difference}|}{\text{Distance Difference}} \quad (3)$$

in equation (3), the modulus Elevation Difference over Elevation Difference fraction is to obtain a positive or negative value for the slope since the *arcsin* function will always return a positive value and this is not true when driving a vehicle on a uphill and downhill journey. Therefore, for a downhill slope, the Elevation Difference fraction will return a negative value and for an uphill slope, it will return a positive value.

Equation (3) can also be rewritten as:

$$\angle(\theta) = \frac{|\Delta e|}{\Delta e} \times \arcsin \frac{|\Delta e|}{\Delta d}$$

To convert and calculate the angle from degrees to percentage, the mathematical trigonometry Law of Tangents function for a right angle(90º) triangle will be used as below (Stewart et al., 2006):

$$\tan\theta = \frac{\text{OppositeLength}}{\text{Adjacent Length}}$$

the value of θ is obtained and calculated from equation (3)

$$\tan\theta = \frac{\text{Slope}\,(\%)}{100}$$

$$\angle(\%) = \tan\theta \times 100\,\% \tag{4}$$

Both equations (3) and (4) are calculated in degrees, and not radians.

The next step in the calculation process is to compute the traction power required for the electric vehicle to move up different slope grades. In a vehicle traction application, torque (and thus power) is a function of velocity, acceleration, and road slope. This function is called the road load equation (Greaves et al., 2006):

$$P = mav + mgv\sin\alpha + C_{RR}mgv\cos\alpha + \frac{1}{2}\rho C_D A v^3 \tag{5}$$

where

P = traction power ($kgm^2/s^3 = Js^{-1} = W$)

v = velocity (ms^{-1})

a = acceleration (m/s^2)

α = slope angle (100 sin α = % slope)

m = mass (kg)

g = acceleration due to gravity (m/s^2)

C_{rr} = coefficient of rolling resistance

ρ = density of air (kg/m^3)

C_d = coefficient of aerodynamic drag

A = frontal area of vehicle (m^2)

From this new equation, the value of traction power, kW operating under any slope angle for the Proton Saga EV can be obtained.

The road load equation is separated into four main parts:

($m\ a\ v$), where the acceleration factor is taken into consideration,

($m\ g\ v \sin \alpha$), is the hill climbing factor of an electric vehicle,

($C_{rr}\ m\ g\ v \cos \alpha$), takes into account the rolling resistance, and

($\frac{1}{2}\ \rho\ C_d\ A\ v^3$), is where the aerodynamic drag is considered into the calculation.

The four main parts that sums up the road load equation shows that the calculation of the traction power of an electric vehicle moving on different slope angles is very complete and comprehensive. The more parameter values that are taken into consideration for the road load equation calculations, the more accurate the simulation of range prediction for an electric vehicle.

Before further calculations are preceded, it is important to prove the International System of Units (S.I. units) that are used for all the parameters available in the road load equation. This is important to ensure accurate representation of parameter values for the calculation of the slope angles and traction power of the vehicle later on.

$$P = (m\ a\ v) + (m\ g\ v \sin \alpha) + (C_{rr}\ m\ g\ v \cos \alpha) + (\tfrac{1}{2}\ \rho\ C_d\ A\ v^3)$$

$$W = (kg.\ m/s^2.\ m/s^1) + (kg.\ m/s^2.\ m/s^1) + (kg.\ m/s^2.\ m/s^1) + (kg/m^3.m^2.\ (m/s^1)^3)$$

$$Js^{-1} = (kg.m^2/s^3) + (kg.m^2/s^3) + (kg.m^2/s^3) + (kg.m^2/s^3)$$

$$kg.m^2/s^3 = (kg.m^2/s^3)\ [proven]$$

After the S.I. units were determined, the values for each and every parameter in the equation can be obtained as shown in Table 3.1:

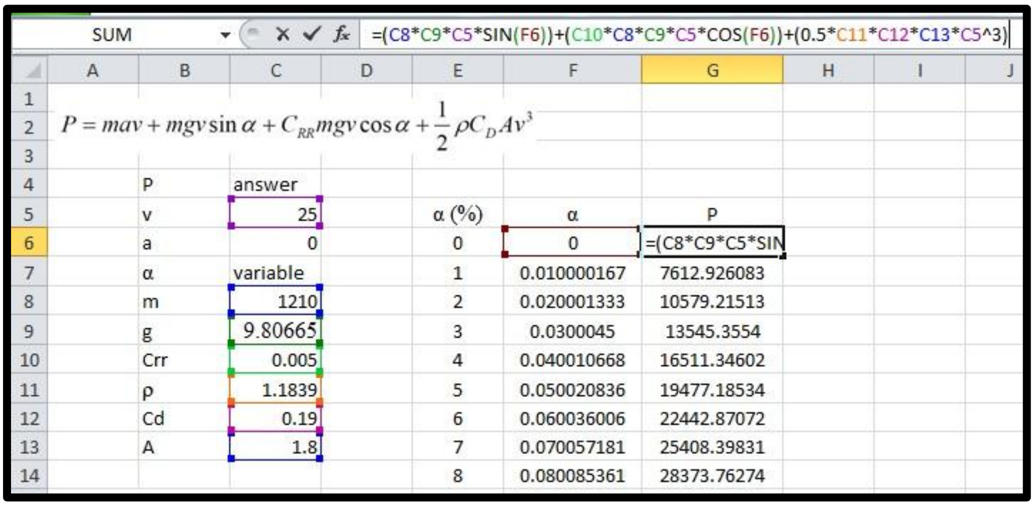
Table 3.1: Road Load Equation parameters and values (Density of Air, 2012)

Parameters	Value
P = traction power	To be calculated
v = velocity	90km/h – 25m/s^1
a = acceleration	0 (m/s^2)
α = slope angle	0% - 30% (variable)
m = mass	1210kg
g = acceleration due to gravity	9.80665 m/s^2
Crr = coefficient of rolling resistance	0.005
ρ = density of air	1.1839 kg/m^3 (at 25ºC)
Cd = coefficient of aerodynamic drag	0.19
A = frontal area of vehicle	1.8m^2

The traction power, P will be calculated in the equation. The velocity of the vehicle is assumed to be constant at 90km/h which is $25m/s^1$. The value 90km/h is selected because it is the average value of maximum speed limit on the Malaysia's highway which falls within the range of 80km/h to 110km/h. When the velocity is constant at 90km/h, the acceleration is 0. The slope angle, α is the variable in the road load equation that values fall between the range of 0% to 30%. The mass of the vehicle is 1148kg. An adult is assumed to be driving the vehicle with an average mass of 62kg. Therefore, the total mass value in the equation will be 1210kg. The acceleration due to gravity, g is a constant with value 9.80665 m/s^2. The vehicle is assumed to have good tyres with coefficient of rolling resistance, C_{rr} of 0.005. The density of air, ρ in Malaysia at an average temperature of 25ºC is 1.1839 kg/m^3. The vehicle is assumed to have a low coefficient of aerodynamic drag, C_d of 0.19 and a frontal area of $1.8m^2$.

Some of these parameter values are based loosely on the GM EV1 and the UltraCommuter electric vehicle published in the research paper, "Vehicle Energy Throughput Analysis as a Drivetrain Motor Design Aid", therefore the assumed parameter values are reasonable and fall within the range of practical electric vehicles available in the current market (Greaves et al., 2006).

Finally, all the measured values of slope angles obtained from Google Earth can be inserted into the new road load equation above to determine the amount of traction power, kW that the Proton Saga EV consumes while moving up different slope angles on a hill and an example of the results calculated in an Excel spread sheet are shown in Figure 3.9:


SUM =(C8*C9*C5*SIN(F6))+(C10*C8*C9*C5*COS(F6))+(0.5*C11*C12*C13*C5^3)

	A	B	C	D	E	F	G	H	I	J
1										
2	$P = mav + mgv\sin\alpha + C_{RR}mgv\cos\alpha + \frac{1}{2}\rho C_D A v^3$									
3										
4		P	answer							
5		v	25		α (%)	α	P			
6		a	0		0	0	=(C8*C9*C5*SIN			
7		α	variable		1	0.010000167	7612.926083			
8		m	1210		2	0.020001333	10579.21513			
9		g	9.80665		3	0.0300045	13545.3554			
10		Crr	0.005		4	0.040010668	16511.34602			
11		ρ	1.1839		5	0.050020836	19477.18534			
12		Cd	0.19		6	0.060036006	22442.87072			
13		A	1.8		7	0.070057181	25408.39831			
14					8	0.080085361	28373.76274			

Figure 3.9: Road Load Equation Calculation in an Excel Spread Sheet

An example of a calculation formula done in the Excel spread sheet is shown below (for $\alpha = 1\%$):

$$P = (m\ a\ v) + (m\ g\ v\ \sin\alpha) + (Crr\ m\ g\ v\ \cos\alpha) + (\tfrac{1}{2}\ \rho\ Cd\ A\ v^3)$$

$$P = (1210 * 0 * 25) + (1210 * 9.80665 * 25 * \sin 0.01) + (0.005 * 1210 * 9.80665 * 25 * \cos 0.01) + (\tfrac{1}{2} * 1.1839 * 0.19 * 1.8 * 25^3)$$

$$P = 0 + (2966.462) + (1483.182) + (3163.233)$$

$$P = 7612.877W$$

From the example shown above, it is tedious to calculate each and every power for its corresponding slope angle one by one manually, therefore the Excel spread sheet is used to simplify the calculation process by just inserting the road load equation and parameter values into the function column of the Excel spread sheet. It is also definitely more accurate because the Excel spread sheet can compute the results by taking in parameter values that have up to nine decimal places. Moreover, this method saves time and all the data calculated and collected can be tabulated into a graph easily as shown in Figure 3.10.

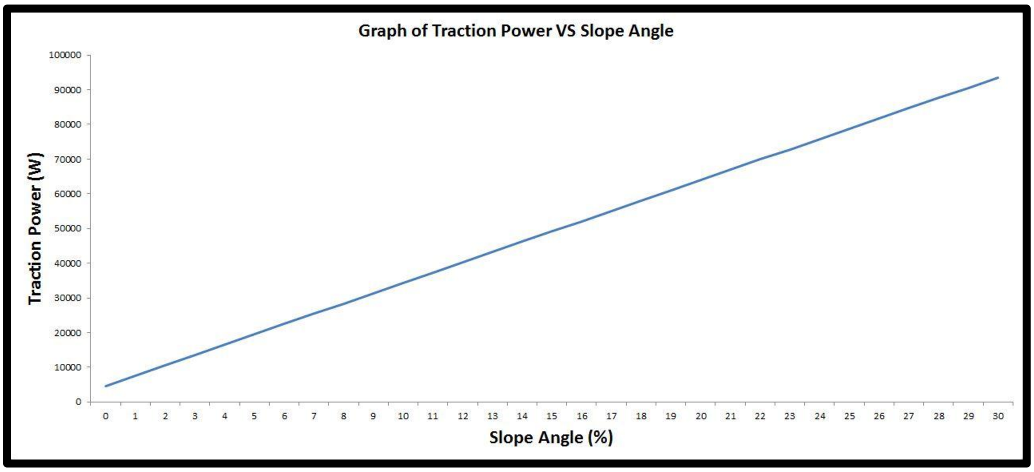


Figure 3.10: Graph Generated from the Calculations of the Road Load Equation

From the graph generated from the calculations of the road load equation above, the graph of Traction Power VS Slope Angle is a linear straight line graph. From this linear straight line graph, an equation can be computed from the straight line mathematical equation, Y=mX+C. taking two points from the straight line graph, the y-intersect (0%, 4646.488625W) and (25%, 78742.69071W), the new road load equation can be produced as below:

$$Y = mX + C$$

$$78742.69071 = m(25) + 4646.488625$$

$$m = (78742.69071 - 4646.488625)/25$$

$$m = 2963.848083$$

Therefore, the new road load equation is:

$$Y = 2963.848083X + 4646.488625 \tag{6}$$

From this new road load equation, any slope angles can be represented by the X variable to calculate the corresponding traction power represented by the Y variable. From here onwards, any slope angles from Google Earth can be calculated by the new road load equation above to determine the amount of traction power, kW that the electric vehicle consumes while moving on different slope angles on the road. This new road load equation was also included into the MATLAB programming for range prediction results simulation at the end of this research.

Apart from the traction power, the time taken to drive up the hill for different slope angles must also be calculated. To calculate the time taken (hours) for every data samples, all the calculations are based on the total power and energy needed for the electric vehicle to travel at a constant 90km/h up slopes of varying angles up to 25°. Therefore, the formula to calculate the time taken for each sample is as below:

$$\text{Time taken(h)} = \frac{\text{Distance difference(m)}}{\text{90 km/h}}$$

$$\text{Time taken(h)} = \frac{\text{Distance difference(m)}}{\text{90,000 m/h}} \tag{7}$$

After all the data collections have been calculated, the energy used by the Saga EV for each data sample can be calculated using the formula below:

Energy used (kWh) = Traction power (kW) x Time taken (h) (8)

Finally, all these equations, formulas and steps from (1) to (8) will be used in the MATLAB programming and functions for the CPS simulation results.

3.9 Conventional Distance Estimation Method for an EV

As mentioned earlier, the conventional distance estimation method adopted by most current electric vehicles nowadays are based on a ratio basis between the total distances travelled to the total battery energy consumed in either percentage (%) or kilo Watt hours (kWh). The longer the total distances travelled, the more battery energy is consumed by the electric vehicle and this relationship increases linearly and in proportional to one another. An example of this relationship is shown in Figure 3.11 below:

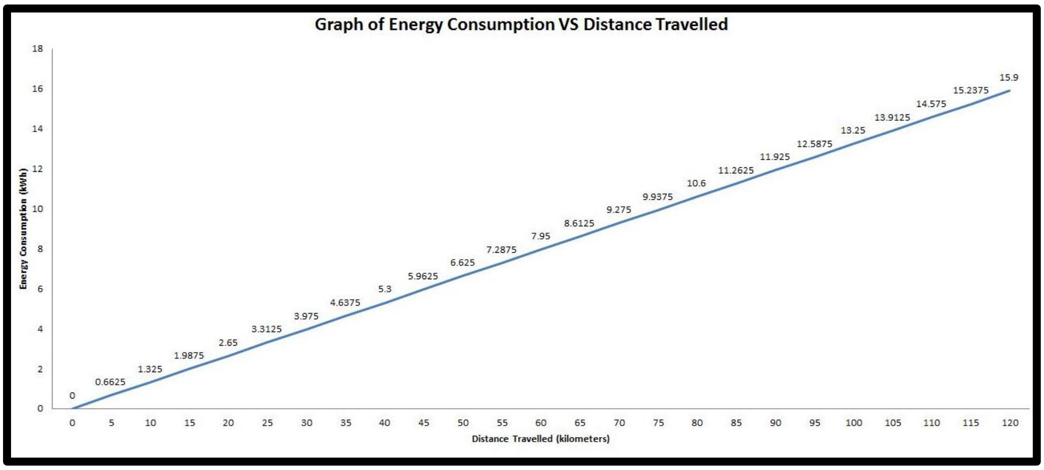


Figure 3.11: Graph of Energy Consumption VS Distance Travelled

From Figure 3.11 above, it can be observed that the relationship between the distance travelled and energy consumption of an electric vehicle is linear and proportional to each other. From the same graph, an equation can be derived from the standard Y = mX + C equation as below:

$Y = mX + C$, $Y = 15.9kWh$, $X = 120km$

$15.9 = m(120) + 0$

$m = 0.1325$

Therefore, $Y = 0.1325X$ is the conventional distance estimation method formula, where Y is the energy consumption of the electric vehicle and X is the total distance travelled.

From Figure 3.11, another question that can be raised is, how was the energy consumption and distance travelled results of the graph produced by the car manufacturer? Was it produced based on a zero gradient flat road? Highway? Downhill or uphill driving profile? Most common distance estimation methods do not have different and specific driving profile results such as for downhill or uphill driving. Therefore, the graph results produced in Figure 3.11 is assumed to be for a highway driving profile where there is a fair share of uphill and downhill for a distance travelled. This also means that the results produced in Figure 3.11 is the average energy consumption for an electric vehicle which moves on a highway with an equal amount of uphill and downhill slope gradients. A good example is shown in Figure 3.12 below:

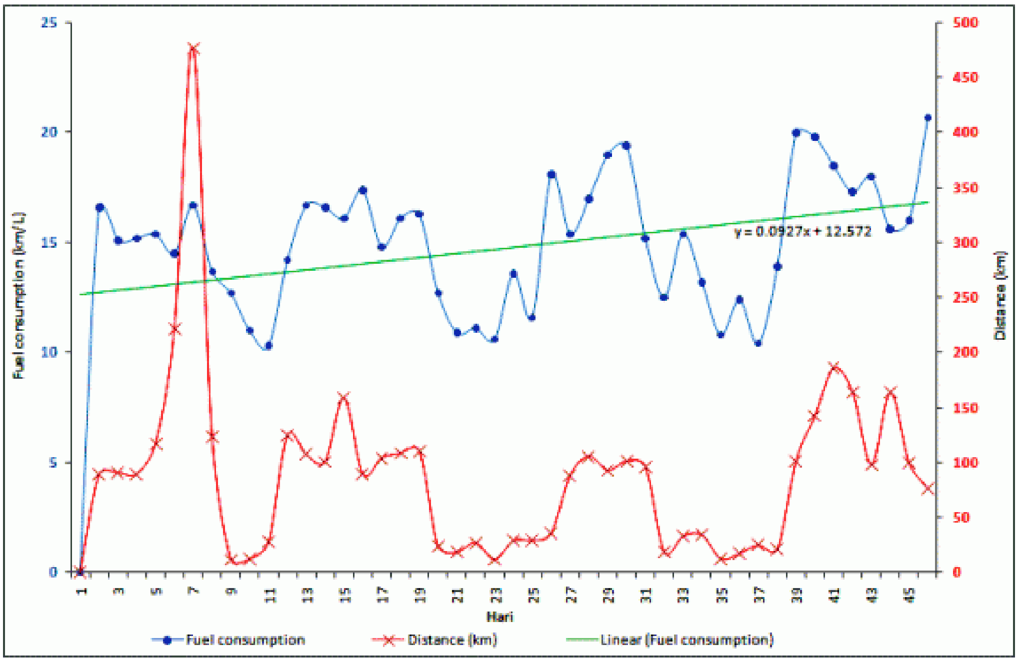


Figure 3.12: Fuel Consumption Graph of a Honda Civic Hybrid

In Figure 3.12, the user drives his Honda Civic Hybrid for a total of 45 days with difference distance travelled every day (Parasolx, 2012). He recorded the average fuel consumption for his vehicle in kilometres per litre every day for 45 days and this is shown in the blue graph in Figure 3.12. The driving condition for the 45 days are tested over many different driving conditions such as highway, downhills, uphills, driving in the city etc. At the end of the experiment, the user produces another linear graph where it is the total average fuel consumption for the complete 45 days and these results are shown in the green graph in Figure 3.12. Therefore, this is a good example where fuel consumption of a vehicle is recorded for many different driving profiles such as uphill, downhill, and highway after a period of 45 days and average linear fuel consumption is produced when the experiments and testing done are completed.

From the results discussed above, it can be safely assumed that a complete conventional distance estimation method for an electric vehicle will look something like Figure 3.13.

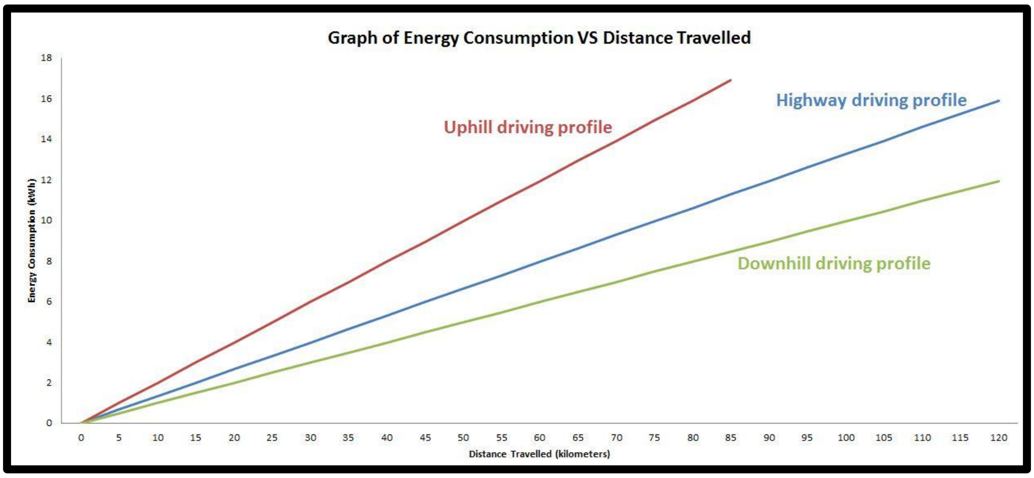


Figure 3.13: Prediction Complete Graph of Energy Consumption VS Distance Travelled for an Electric Vehicle

From Figure 3.13, the red graph shows an uphill driving profile where the energy consumption of an electric vehicle is higher and will cover less distance for the same amount of battery energy compared to the average energy consumption. The green graph shows a downhill driving profile where the energy consumption of an electric vehicle is lower and can cover much more distance for the same amount of battery energy of 15.9kWh compared to the average energy consumption. The blue graph shows the highway driving profile which is the average energy consumption graph similar to Figure 3.11 where it is assumed that most current conventional distance estimation method for electric vehicles in the market now is using this type of driving profile to represent the energy consumption of their electric vehicles. The red and green graph in Figure 3.13 is just a prediction graph to complete the energy consumption versus the distance travelled graph of an electric vehicle but it is a very reasonable assumption based on the results from the blue graph.

As can be seen in Figure 3.13, to accurately estimate the energy consumption for an electric vehicle for different driving profiles, at least three different graphs are needed. Therefore, the average energy consumption graph in Figure 3.11 is not a good representation of an electric vehicle's energy consumption if the vehicle is moving on a road which is mostly uphill or downhill. In fact, it will be totally wrong to estimate it using this method because as can be seen in Figure 3.13, uphill and downhill driving conditions have their own driving profiles to be used and calculated. Therefore for the conventional distance estimation method, it is not accurate to estimate different driving profiles using an average energy consumption calculation to simulate different driving conditions. To summarize, there is no clear techniques or algorithms that the conventional distance estimation method uses to accurately estimate the energy consumption of an electric vehicle that moves on different driving conditions.

This is a severe problem that is needed to be solved for electric vehicles and here is where the Contour Positioning System (CPS) comes into the picture. The CPS consists of one algorithm that currently utilizes MATLAB programming to estimate accurately and precisely the energy consumption of an electric vehicle that moves on different driving conditions. This algorithm takes into account the road gradient or slope angles in the distance estimation calculations of an electric vehicle and the program will simulate an accurate result for any driving conditions when the vehicle is moving. This new method of distance estimation will be explained further in the results and discussions section of this research.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Main Case Study Simulation Results

	A	B	D	E	F	G	H	I	J
1	Distance(m)	Elevation(m)	Distance Difference(m)	Elevation Difference(m)	Calculated Slope(degree)	Calculated Slope(%)	Traction Power(kW)	Time Taken(hour)	Energy Used(kWh)
2	10	1496.447754	0	0	0	0	0	0	0
3	20	1496.956665	10	0.50891113	2.917106086	5.095714287	19.75372767	0.000111111	0.002194859
4	30	1497.470215	10	0.5135498	2.943718507	5.142283436	19.89179099	0.000111111	0.002210199
5	40	1497.988159	10	0.51794434	2.968930921	5.186404761	20.02259726	0.000111111	0.002224733
6	50	1498.51062	10	0.52246094	2.994844219	5.23175472	20.15704606	0.000111111	0.002239672
7	60	1499.03772	10	0.52709961	3.021458513	5.278333703	20.29513854	0.000111111	0.002255015
8	70	1499.569336	10	0.53161621	3.047373059	5.323690217	20.42960677	0.000111111	0.002269956
9	80	1500.105469	10	0.53613281	3.07328823	5.369050008	20.56408471	0.000111111	0.002284898
10	90	1500.548706	10	0.4432373	2.540394932	4.43673333	17.80005012	0.000111111	0.001977783
11	100	1500.977539	10	0.42883301	2.457785854	4.292278618	17.37178596	0.000111111	0.001930198
501	5000	1622.681519	10	0.5505371	3.15594083	5.513733158	20.99302613	0.000111111	0.002332558
502	5010	1623.232178	10	0.55065918	3.15664136	5.514959531	20.99666195	0.000111111	0.002332962
503	5020	1623.782715	10	0.55053711	3.155940887	5.513733259	20.99302642	0.000111111	0.002332558
504	5030	1624.333252	10	0.55053711	3.155940887	5.513733259	20.99302642	0.000111111	0.002332558
505	5040	1624.883911	10	0.55065918	3.15664136	5.514959531	20.99666195	0.000111111	0.002332962
506	5050	1625.434448	10	0.55053711	3.155940887	5.513733259	20.99302642	0.000111111	0.002332558
507	5060	1625.985107	10	0.55065918	3.15664136	5.514959531	20.99666195	0.000111111	0.002332962
508	5070	1626.535645	10	0.55053711	3.155940887	5.513733259	20.99302642	0.000111111	0.002332558
509	5080	1627.025024	10	0.48937988	2.805060583	4.899669492	19.17251464	0.000111111	0.002130279
510	5090	1627.037598	10	0.01257325	0.072039435	0.125732599	5.019247809	0.000111111	0.000557694
511	0	0	0	0	0	0	0	0	0.864318654
512	0	0	0	0	0	0	0	0	5.435966379

Figure 4.1: Simulation results from Berinchang to Equatorial Hotel extracted into a table form using MATLAB

The CPS calculations are done by data extraction using Python programming and MATLAB simulations. Therefore, a set of instructions and codings are designed to perform the necessary CPS functions.

Figure 4.1 shows the complete simulation results from Berinchang to Equatorial Hotel extracted into an Excel spread sheet using MATLAB. The distance and elevation column data are extracted from Google Earth's elevation profile using Python programming. These two columns of data will then be used to simulate the complete results in Figure 4.4 using MATLAB. In Figure 4.1, all the data samples from line 12 to 500 are hidden because it is too lengthy to be displayed. Therefore, those sample values shown in Figure 4.1

are the first and last ten data samples from the complete simulation as can be seen by looking at the Distance(m) column. The highlighted figures in lines 511 and 512 are the total energy used in kWh and percentage respectively.

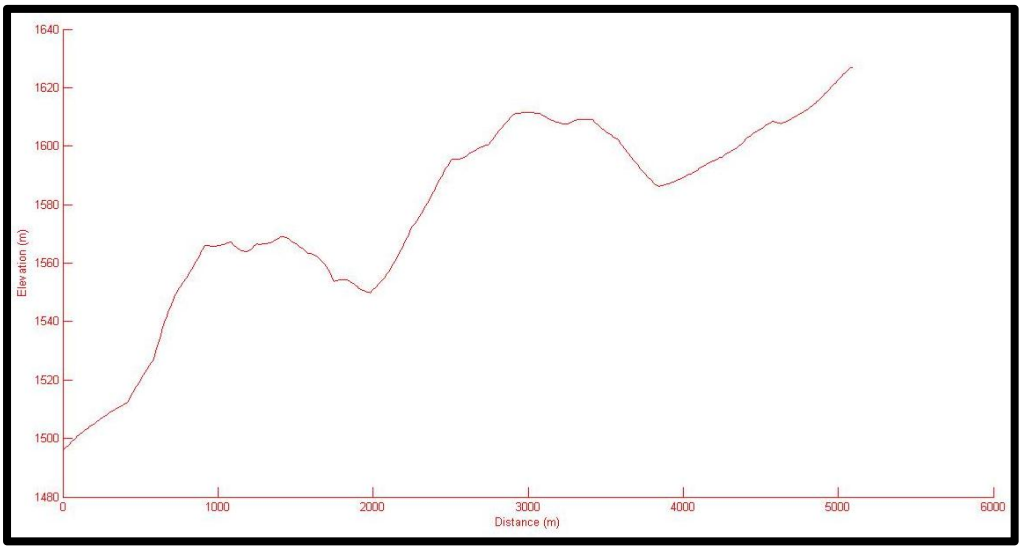


Figure 4.2: Simulation results for elevation graph in MATLAB from Berinchang to Equatorial Hotel

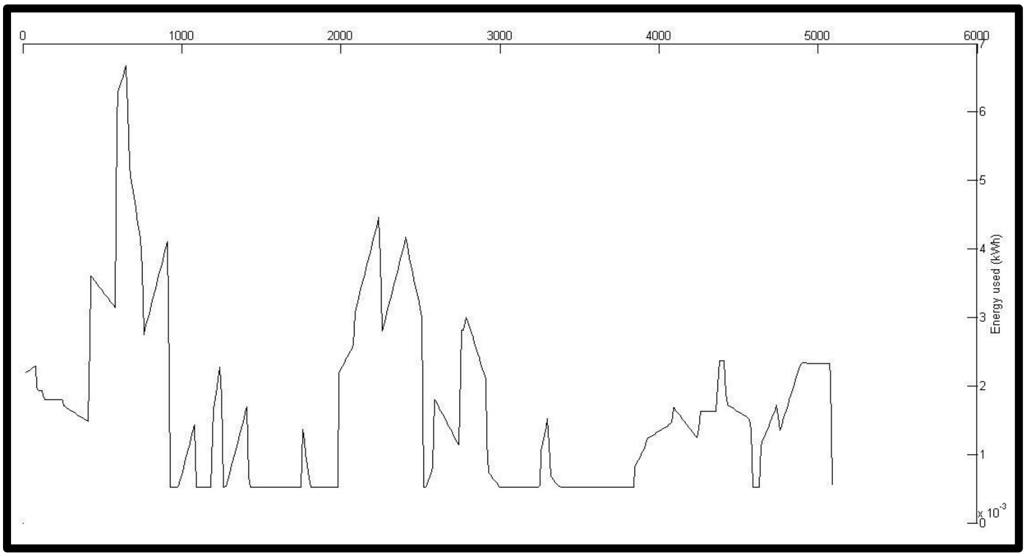


Figure 4.3: Simulation results for energy used graph in MATLAB from Berinchang to Equatorial Hotel

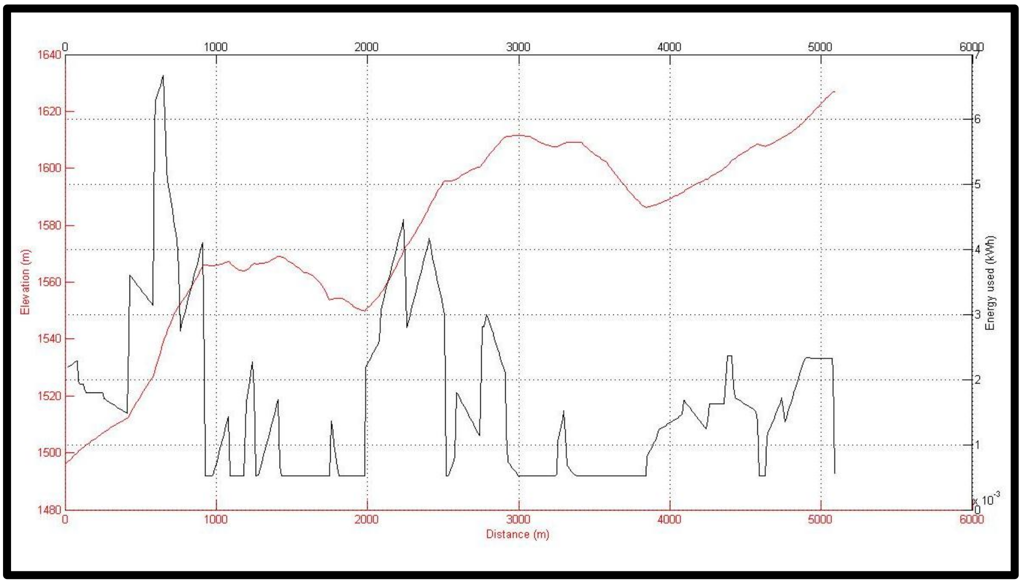


Figure 4.4: Simulation results for elevation and energy used graph in MATLAB from Berinchang to Equatorial Hotel

Figure 4.2 and Figure 4.3 illustrates the simulation results for elevation and energy used graphs in MATLAB respectively from Berinchang to Equatorial Hotel. Figure 4.4 shows the simulation results for elevation and energy used graphs in MATLAB from Berinchang to Equatorial Hotel. The elevation graph is red in colour and the energy used graph is in black. Both the graphs are plotted into one diagram to make it convenient to view the energy used by the vehicle at the respective elevation easily. For example, at a distance of around 700m, the elevation of the road at 1540m is the steepest in the graph. Respectively, the energy used at that point is also the highest with around $5x10^{-3}$ kWh.

4.1.1 Comparisons between Conventional Distance Estimation Method and CPS

The conventional distance estimation method is a distance estimation that does not consider the road elevation into their calculations. Therefore, the CPS was designed to solve this problem and include road elevation calculations into the distance estimation simulations.

Figure 4.5 shows the simulation results for the CPS distance estimation:

Figure 4.5: MATLAB simulation results for the CPS distance estimation

Figure 4.5 shows the simulation results that are obtained from MATLAB when the electric vehicle is moving uphill for 5.09 kilometres. The results displayed are total energy needed in kWh (kilo Watt hours) and in % (percentage).

Distance estimation without road elevation calculations:

$Y = 0.1325X$,

where Y is energy used in kWh and X is distance travelled in kilometres

Y = 0.1325 (5.09)

Y = 0.674425kWh of energy used or 4.24%.

The results validation comparison table is shown in Table 4.1 below:

Table 4.1: Calculation and Simulated Energy Used Results from Berinchang to Equatorial Hotel

Method Used	Energy Used (15.9kWh-100%)	
Distance estimation without road elevation	0.67443kWh	4.24%
Distance estimation with road elevation (CPS)	0.864319kWh	5.44%

The distance estimation without road elevation result is what the Saga EV estimates before the journey from Berinchang to Equatorial Hotel begins. The distance estimation with road elevation(CPS) result is the real energy consumption when the Saga EV travels from Berinchang to Equatorial Hotel for 5.09 kilometres. From the results above, the extra energy needed when the Saga EV travels on an uphill condition can be calculated below:

$$\text{Percentage difference} = \left|\frac{\text{CPS - Conventional}}{\text{Conventional}}\right| \times 100\%$$
$$= \left|\frac{5.44 - 4.24}{4.24}\right| \times 100\%$$
$$= 28.30\%$$

From the calculations above, the uphill journey consumes an additional 28.30% of battery energy compared to the distance estimations done by the conventional method. This extra energy consumption depends on the steepness of the road slope. The steeper the road slope, more energy will be drained from the vehicle's battery.

4.2 MATLAB Simulations (Nine Case Studies)

4.2.1 MATLAB Simulation for Vehicle Moving Downhill 5km

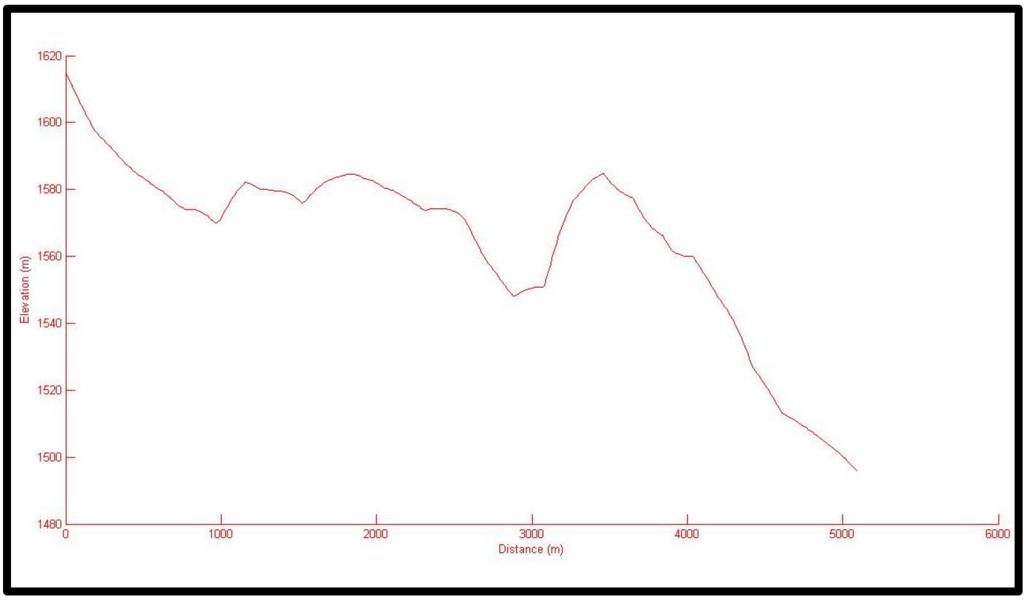


Figure 4.6: Elevation MATLAB Simulation for Vehicle moving downhill 5km

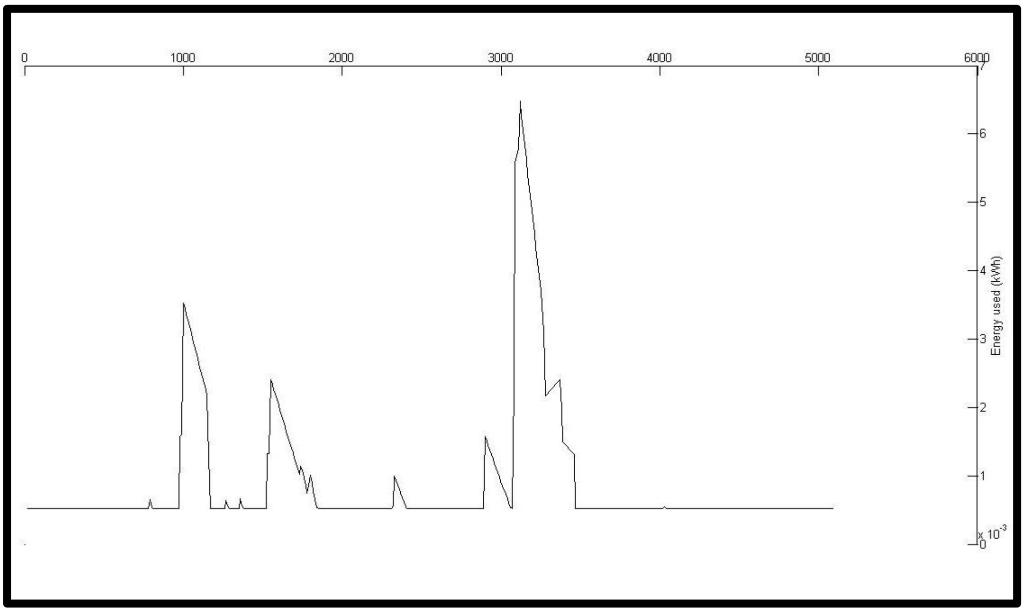


Figure 4.7: Energy Consumption MATLAB Simulation for Vehicle moving downhill 5km

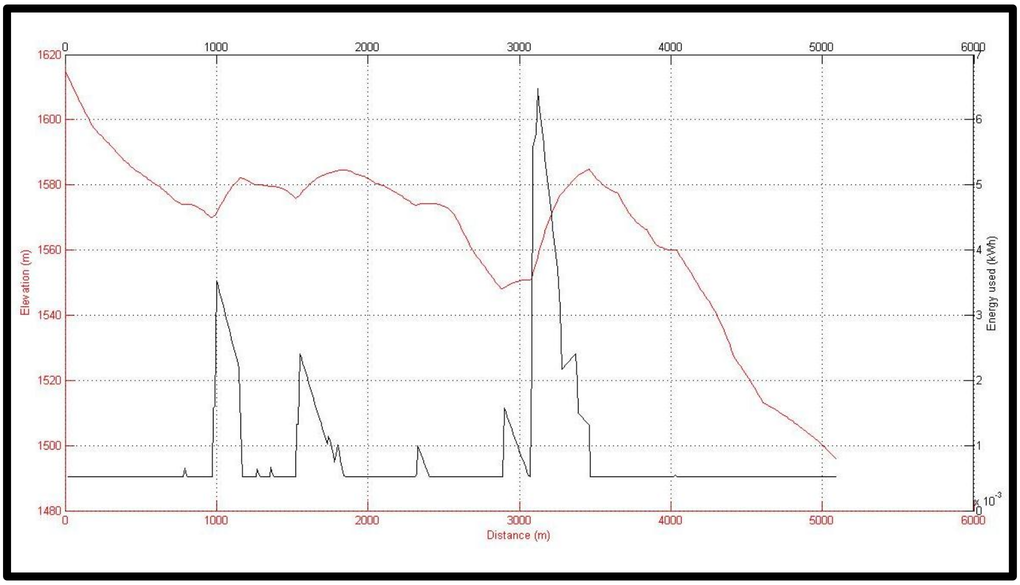


Figure 4.8: MATLAB Simulation graph for Vehicle moving downhill 5km

Figure 4.6 and Figure 4.7 illustrates the elevation and energy consumption MATLAB simulated graphs respectively for vehicle moving downhill 5km. The result displayed in Figure 4.8 is a MATLAB simulation graph for an electric vehicle moving downhill 5 kilometres from a hill slope. From these results, the energy consumption graph displays many low and minimal energy consumption periods such as during 0 to 1000 meters and 3500 to 5000 meters. This is true because when the electric vehicle is moving downhill, very minimal energy is consumed by the vehicle's drive train. These results also correspond with the elevation graph where it is shown that the vehicle is moving downhill from 0 to 1000 meters and 3500 to 5000 meters. There was only a short period where the vehicle is moving uphill right after 3000 to 3500 meters where the energy consumption graph shows a sharp increase in energy used by the electric vehicle.

Figure 4.9: MATLAB simulation results for Vehicle moving downhill 5km

Figure 4.9 shows the simulation results that are obtained from MATLAB when the electric vehicle is moving downhill for 5 kilometres. The results displayed are total energy needed in kWh (kilo Watt hours) and in % (percentage).

Distance estimation without road elevation calculations:

Y = 0.1325X,

where Y is energy used in kWh and X is distance travelled in kilometres

Y = 0.1325 (5)

Y = 0.6625kWh of energy used or 4.17%.

Table 4.2: Calculation and Simulated Energy Used Results for Vehicle moving downhill 5km

Method Used	**Energy Used (15.9kWh-100%)**	
Distance estimation without road elevation	0.6625kWh	4.17%
Distance estimation with road elevation (CPS)	0.455965kWh	2.87%

$$\begin{aligned} \text{Percentage difference} &= \left|\frac{\text{CPS - Conventional}}{\text{Conventional}}\right| \times 100\% \\ &= \left|\frac{2.87 - 4.17}{4.17}\right| \times 100\% \\ &= 31.18\% \end{aligned}$$

Table 4.2 displays the calculation and energy used results when the electric vehicle is moving downhill for 5 kilometres. From the table, it is shown that the distance estimation with road elevation (CPS) consumes a lower energy at 2.87% compared to distance estimation without road elevation at 4.17%. This is because when an electric vehicle is moving downhill, the drive train is supposed to switch off and stop functioning while the regenerative braking function with start to operate at this moment. The conventional method could not tell this difference and will estimate energy consumption based on a distance to battery energy ratio basis. Therefore for this case study, the percentage difference between CPS and the conventional method is calculated to be 31.18%.

4.2.2 MATLAB Simulation for Vehicle Moving on Three 5km Hills

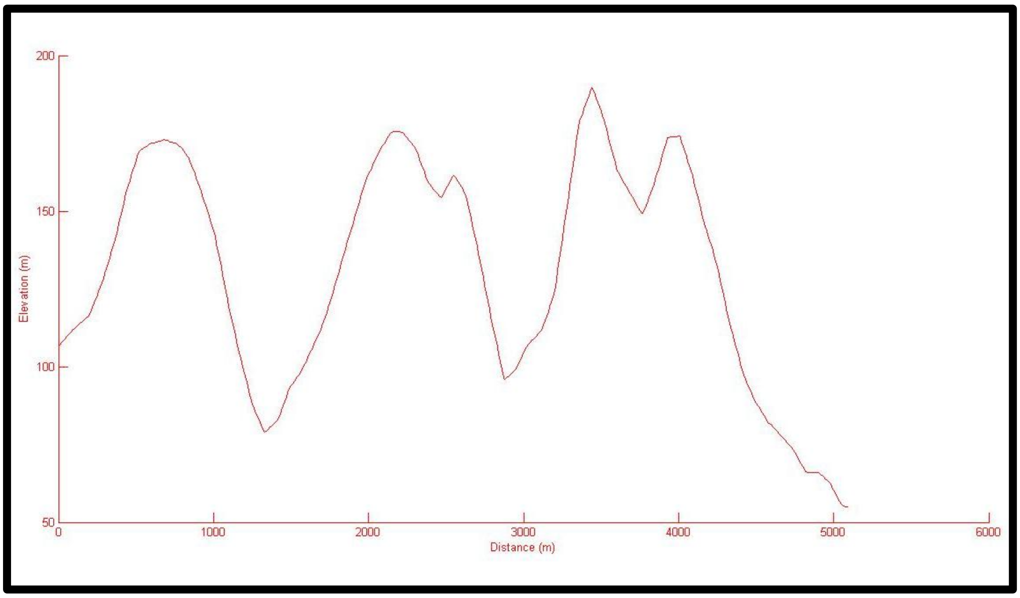


Figure 4.10: Elevation MATLAB Simulation for Vehicle moving on three 5km hills

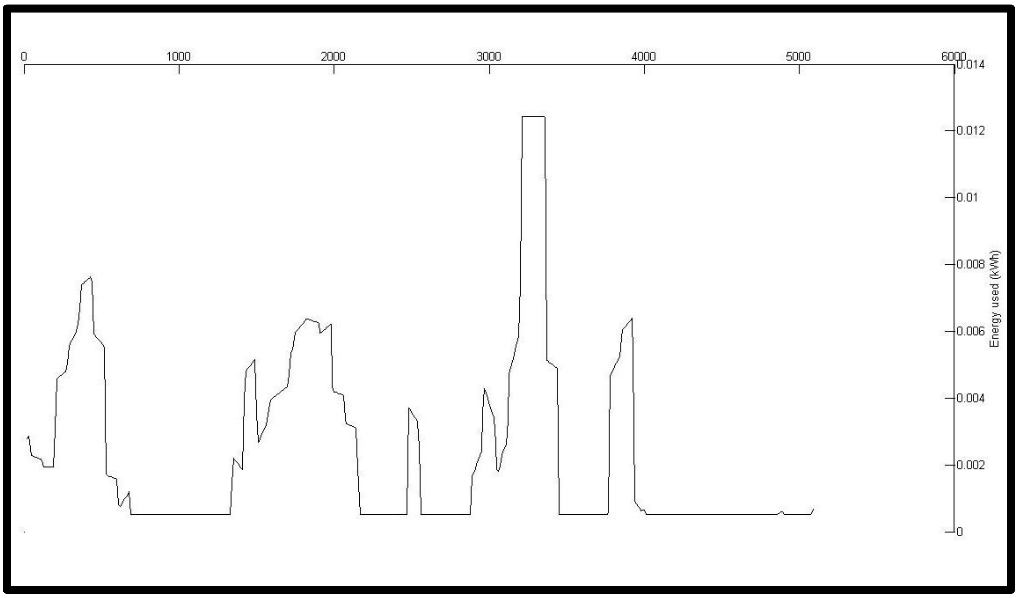


Figure 4.11: Energy Consumption MATLAB Simulation for Vehicle moving on three 5km hills

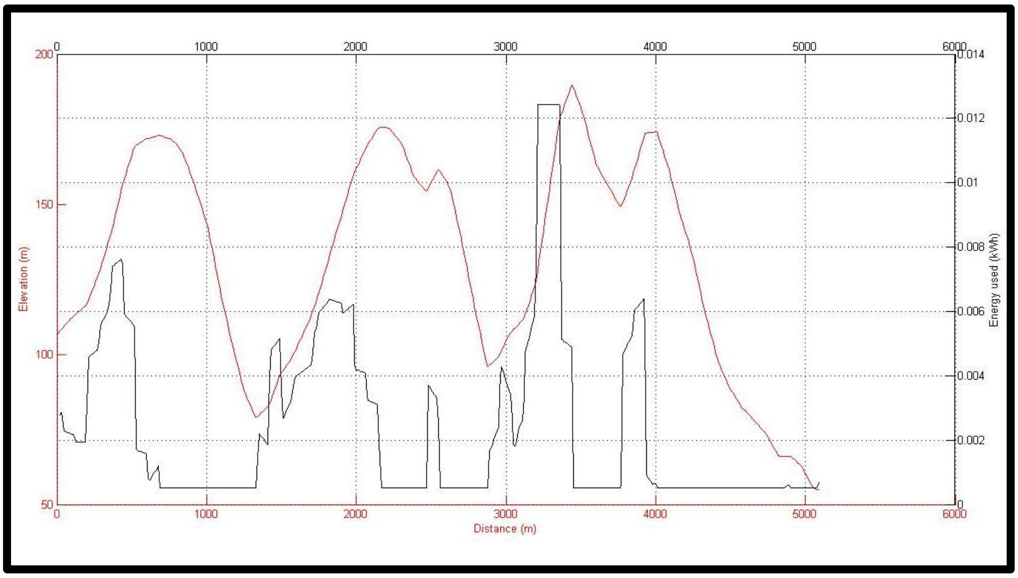


Figure 4.12: MATLAB Simulation Graph for Vehicle moving on three 5km hills

Figure 4.10 and Figure 4.11 illustrates the elevation and energy consumption MATLAB simulated graphs respectively for vehicle moving on three 5km hills. In Figure 4.12 shown above, the result displayed is a MATLAB simulation graph for an electric vehicle moving across three hills for a distance of 5 kilometres. From these results, it is shown that the energy consumption peaks from approximately 0 to 500 meters, 1300 to 2000 meters and 3000 to 3500 meters corresponding to the results from the elevation graph where the electric vehicle is moving up three different slopes. These three segments are where the electric vehicle consumes the most amount of energy throughout the 5 kilometres journey. After the uphill slopes reaching at the peak of the hills, the vehicle will start moving downhill from approximately 800 to 1300 meters, 2200 to 2900 meters and 4000 to 5000 meters where the corresponding energy consumptions are also shown to be at the lowest point and most minimal.

Figure 4.13: MATLAB Simulation Results for Vehicle moving on three 5km hills

Figure 4.13 shows the simulation results that are obtained from MATLAB when the electric vehicle is moving across three small hills for a distance of 5 kilometres. The results displayed are total energy needed in kWh (kilo Watt hours) and in % (percentage).

Distance estimation without road elevation calculations:

Y = 0.1325X,

where Y is energy used in kWh and X is distance travelled in kilometres

Y = 0.1325 (5)

Y = 0.6625kWh of energy used or 4.17%.

Table 4.3: Calculation and Simulated Energy Used Results for Vehicle moving on three 5km hills

Method Used	Energy Used (15.9kWh-100%)	
Distance estimation without road elevation	0.6625kWh	4.17%
Distance estimation with road elevation (CPS)	1.229858kWh	7.73%

$$\text{Percentage difference} = \left|\frac{\text{CPS - Conventional}}{\text{Conventional}}\right| \times 100\%$$
$$= \left|\frac{7.73 - 4.17}{4.17}\right| \times 100\%$$
$$= 85.37\%$$

Table 4.3 displays the calculation and energy used results when the electric vehicle is moving across three small hills for a distance of 5 kilometres. From the table, it is shown that the distance estimation with road elevation (CPS) consumes a much higher energy at 7.73% compared to distance estimation without road elevation at 4.17%. This is because when an electric vehicle is moving up hills, it requires much more energy to propel and push the electric vehicle up the slopes where it drains more current from the battery pack. It can also be noticed that in both Case Study 4.2.1 and 4.2.2, the conventional method estimates the same amount of energy consumption which is 4.17% of energy used for a distance of 5 kilometres but the two driving conditions in both case studies are very different. This shows the limitation of the distance estimation without considering road elevation where it could not provide an accurate distance estimation prediction for different road conditions. Therefore for this case study, the percentage difference between CPS and the conventional method is calculated to be 85.37% where the CPS estimates much higher energy consumption due to the three uphill driving conditions.

4.2.3 MATLAB Simulation for Vehicle Moving 5km on North-South Highway

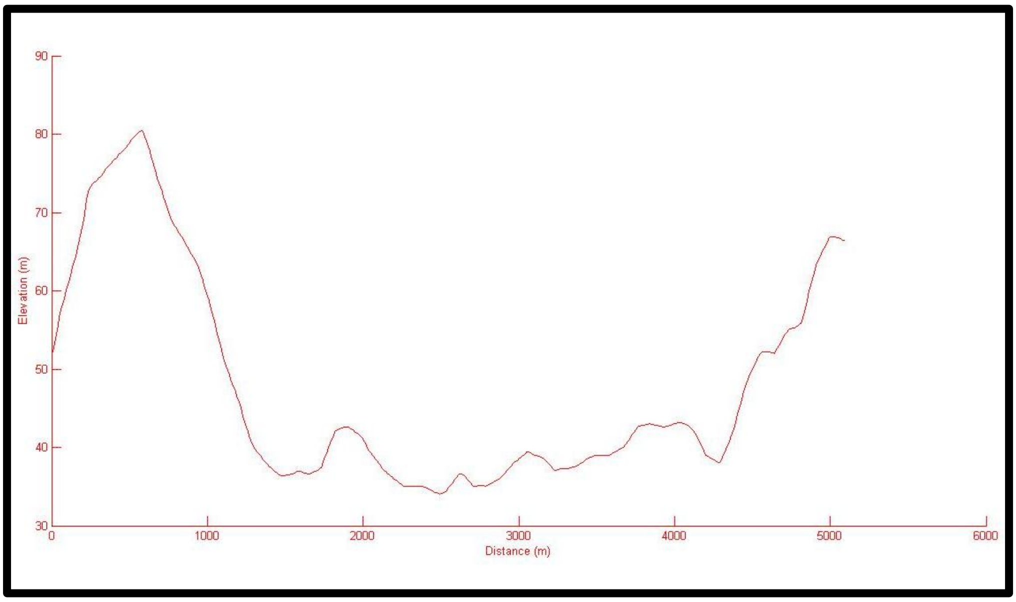


Figure 4.14: Elevation MATLAB Simulation for Vehicle moving 5km on North-South Highway

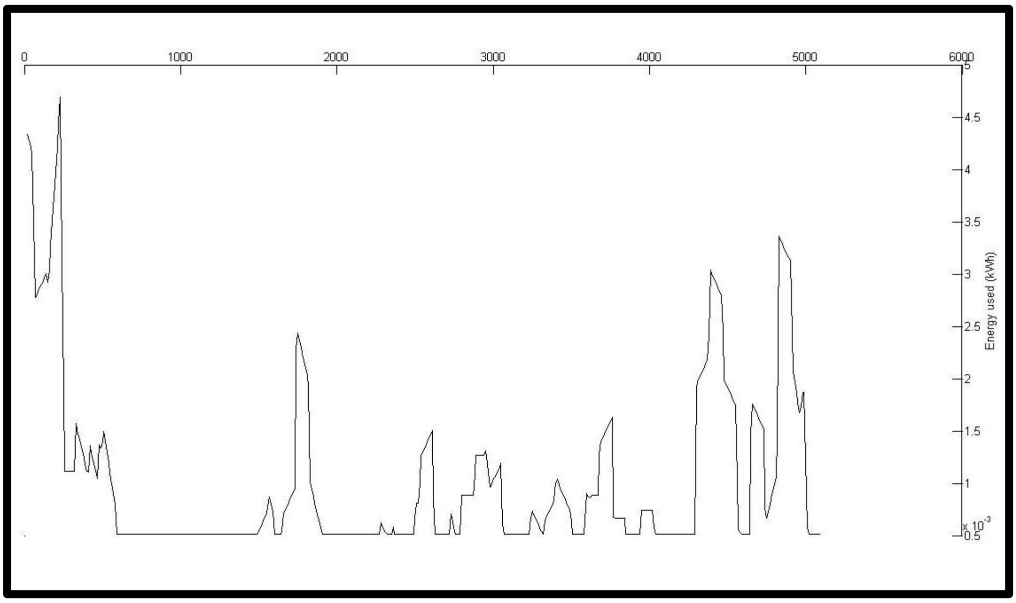


Figure 4.15: Energy Consumption MATLAB Simulation for Vehicle moving 5km on North-South Highway

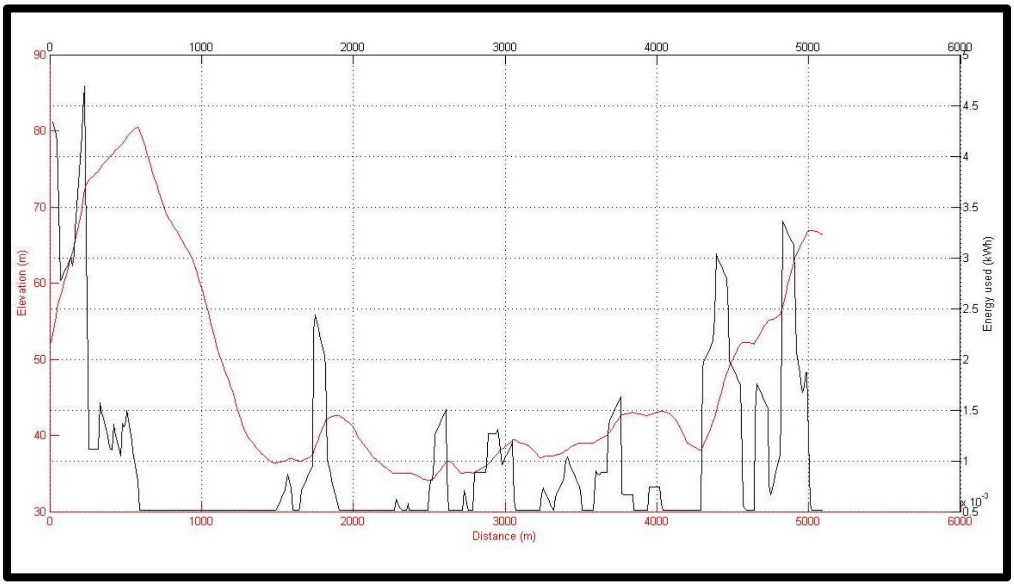


Figure 4.16: MATLAB Simulation Graph for Vehicle moving 5km on North-South Highway

Figure 4.14 and Figure 4.15 illustrates the elevation and energy consumption MATLAB simulated graphs respectively for vehicle moving 5km on the North-South Highway. The two previous case studies were done to analyse moving a vehicle down a hill and across three small hills for a same travelling distance of 5 kilometres and both produced very different results. For this third case study, Figure 4.16 displays the result of a MATLAB simulation graph for an electric vehicle moving on a main highway in Malaysia, also for a distance of 5 kilometres. From these results, it is shown from the energy consumption graph that the energy used by the electric vehicle throughout the 5 kilometres journey is almost constant and well balanced between uphills and downhills. The only obvious energy consumption worth mentioning was between 600 to 1500 meters where the electric vehicle moves downhill for almost 20% of the whole journey.

Figure 4.17: MATLAB Simulation Results for Vehicle moving 5km on North-South Highway

Figure 4.17 shows the simulation results that are obtained from MATLAB when the electric vehicle is moving on the North-South Highway for a distance of 5 kilometres. The results displayed are total energy needed in kWh (kilo Watt hours) and in % (percentage).

Distance estimation without road elevation calculations:

Y = 0.1325X,

where Y is energy used in kWh and X is distance travelled in kilometres

Y = 0.1325 (5)

Y = 0.6625kWh of energy used or 4.17%.

Table 4.4: Calculation and Simulated Energy Used Results for Vehicle moving 5km on North-South Highway

Method Used	Energy Used (15.9kWh-100%)	
Distance estimation without road elevation	0.6625kWh	4.17%
Distance estimation with road elevation (CPS)	0.518422kWh	3.26%

$$\text{Percentage difference} = \left|\frac{\text{CPS - Conventional}}{\text{Conventional}}\right| \times 100\%$$
$$= \left|\frac{3.26 - 4.17}{4.17}\right| \times 100\%$$
$$= 21.82\%$$

Table 4.4 displays the calculation and energy used results when the electric vehicle is moving on the North-South Highway for a distance of 5 kilometres. From the table, it is shown that the distance estimation with road elevation (CPS) consumes energy of 3.26% compared to distance estimation without road elevation at 4.17% where both are almost similar. The results are almost similar because the calculations for the conventional distance estimation method was based on a ratio basis between the total distance to battery energy where it is an average distance estimation assumption more suitable to be applied onto straight roads and highways without considering hill and sloppy conditions. In this case, the conventional method also estimates the same amount of energy consumption which is 4.17% of energy used for a distance of 5 kilometres, similar to both the first and second case studies conducted earlier but all three driving conditions in the three case studies are very different. This once again proves that the conventional distance estimation method without considering road elevation is not suitable to be applied onto different road conditions. For this case study, the percentage difference between CPS and the conventional method is calculated to be 21.82%. The following case studies are also done on the North-South Highway, but for a much longer driving distance of 50 and 100 kilometres.

4.2.4 MATLAB Simulation for Vehicle Moving 50km on North-South Highway

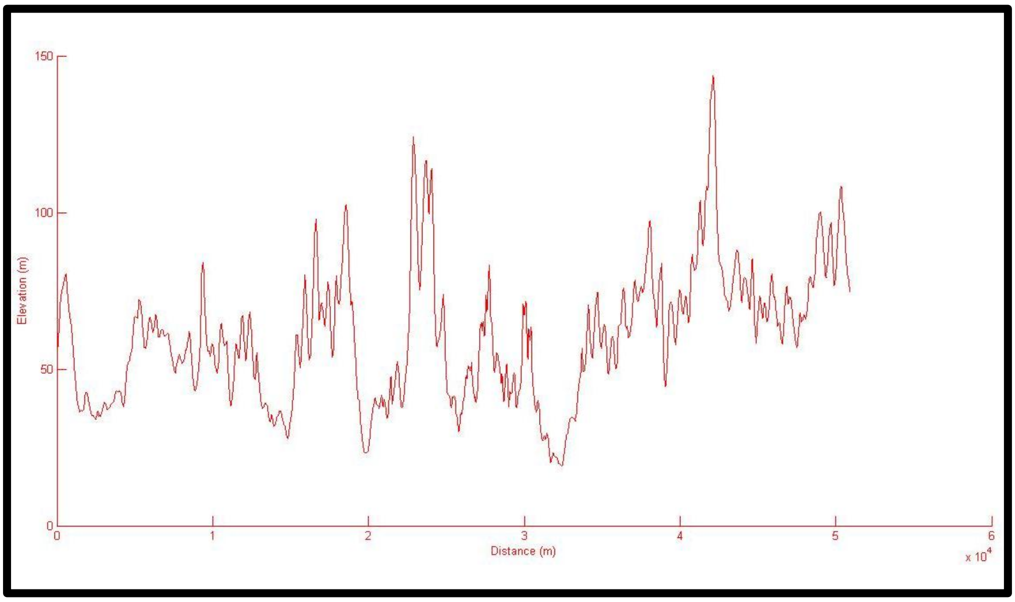


Figure 4.18: Elevation MATLAB Simulation for Vehicle moving 50km on North-South Highway

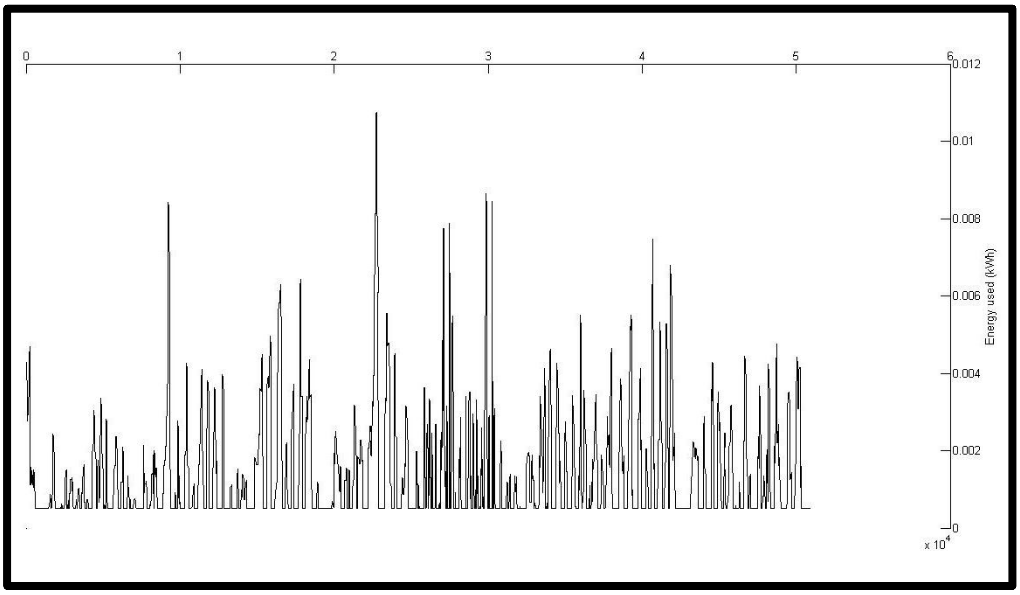


Figure 4.19: Energy Consumption MATLAB Simulation for Vehicle moving 50km on North-South Highway

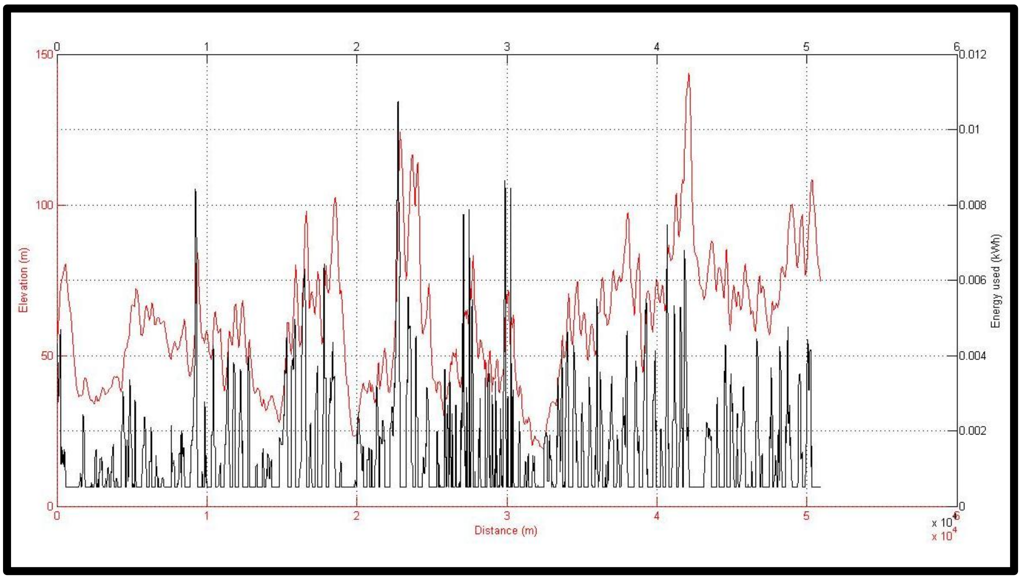


Figure 4.20: MATLAB Simulation Graph for Vehicle moving 50km on North-South Highway

Figure 4.18 and Figure 4.19 illustrates the elevation and energy consumption MATLAB simulated graphs respectively for vehicle moving 50km on the North-South Highway. The three previous case studies were done to analyse moving a vehicle on three different road conditions but for a same travelling distance of 5 kilometres and all three produced very different results. For this fourth case study, Figure 4.20 displays the result of a MATLAB simulation graph for an electric vehicle moving on a main highway in Malaysia, now for a much longer driving distance of 50 kilometres. From these results produced in Figure 4.20, it is hard to analyse from point to point because of the density and large amount of data simulated by MATLAB. However, for a rough overview of the results from the energy consumption graph, the energy used by the electric vehicle throughout the 50 kilometres journey is almost constant and even. The main reason for this observation is because this case study was done on the North-South Highway where there is a well balanced between uphills and downhills road conditions for a long distance of 50 kilometres.

Figure 4.21: MATLAB Simulation Results for Vehicle moving 50km on North-South Highway

Figure 4.21 shows the simulation results that are obtained from MATLAB when the electric vehicle is moving on the North-South Highway for a distance of 50 kilometres. The results displayed are total energy needed in kWh (kilo Watt hours) and in % (percentage).

Distance estimation without road elevation calculations:

Y = 0.1325X,

where Y is energy used in kWh and X is distance travelled in kilometres

Y = 0.1325 (50)

Y = 6.625kWh of energy used or 41.67%.

Table 4.5: Calculation and Simulated Energy Used Results for Vehicle moving 50km on North-South Highway

Method Used	Energy Used (15.9kWh-100%)	
Distance estimation without road elevation	6.625kWh	41.67%
Distance estimation with road elevation (CPS)	7.157795kWh	45.02%

$$\begin{aligned} \text{Percentage difference} &= \left|\frac{\text{CPS - Conventional}}{\text{Conventional}}\right| \times 100\% \\ &= \left|\frac{45.02 - 41.67}{41.67}\right| \times 100\% \\ &= 8.04\% \end{aligned}$$

Table 4.5 displays the calculation and energy used results when the electric vehicle is moving on the North-South Highway for a distance of 50 kilometres. From the table, it is shown that the distance estimation with road elevation (CPS) consumes energy of 45.02% compared to distance estimation without road elevation at 41.67% where both results are very similar to each other. As mentioned earlier in the previous case study, the results are almost similar because the calculations for the conventional distance estimation method was based on an average distance estimation assumption more suitable to be applied onto straight roads and highways without considering hill and sloppy conditions. Therefore in this case study where the analysis was done on the North-South Highway for a long driving distance of 50 kilometres, the results produced for both the CPS and conventional distance estimation method do not produce much differences. For this case study, the percentage difference between CPS and the conventional method is calculated to be 8.04%, which is a very low percentage difference. Therefore, the following case study will also be done on the North-South Highway, but for an even longer driving distance of 100 kilometres to compare the results produced to this case study.

4.2.5 MATLAB Simulation for Vehicle Moving 100km on North-South Highway

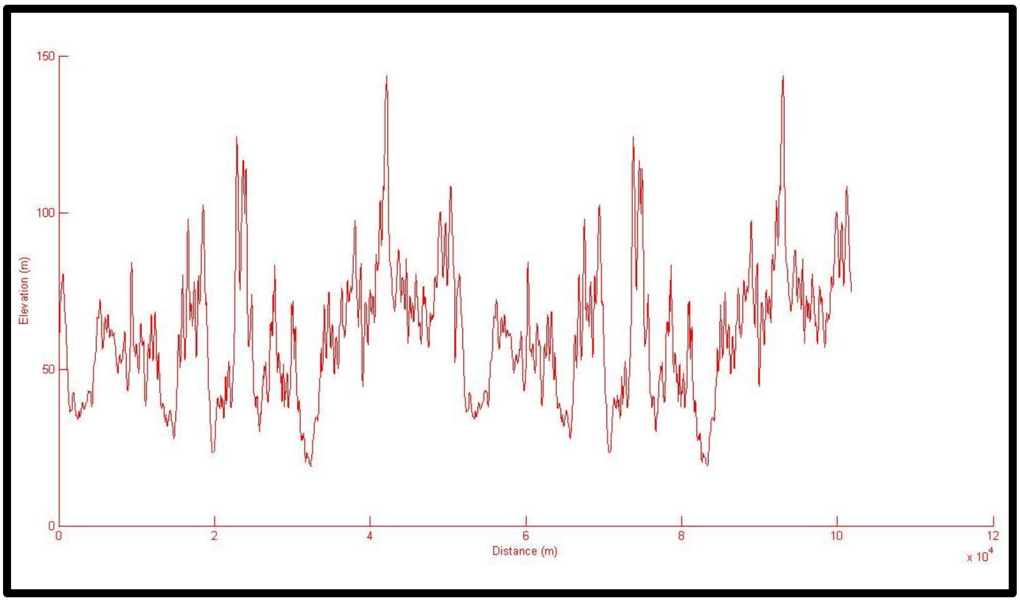


Figure 4.22: Elevation MATLAB Simulation for Vehicle moving 100km on North-South Highway

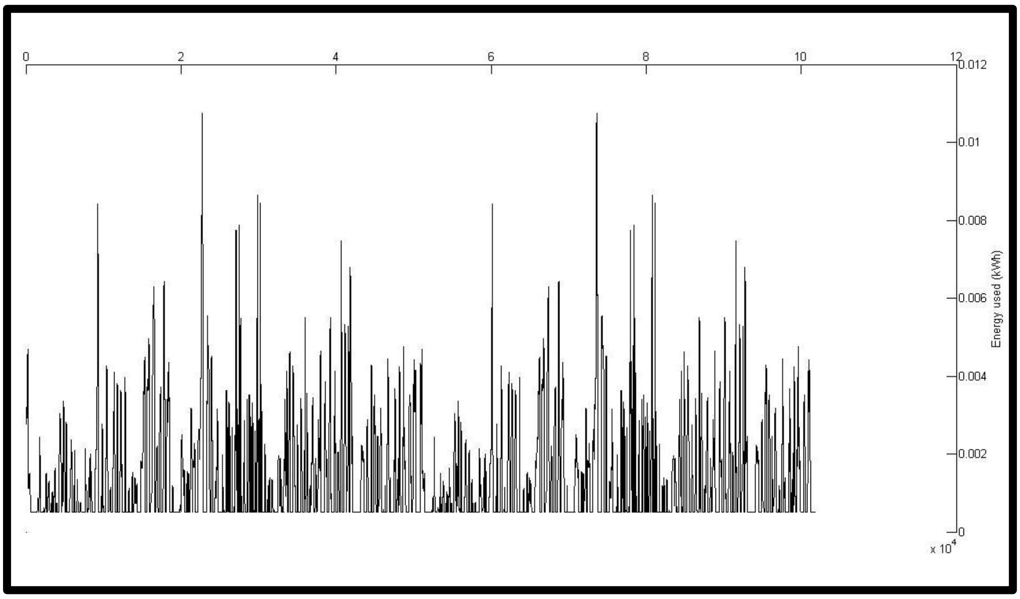


Figure 4.23: Energy Consumption MATLAB Simulation for Vehicle moving 100km on North-South Highway

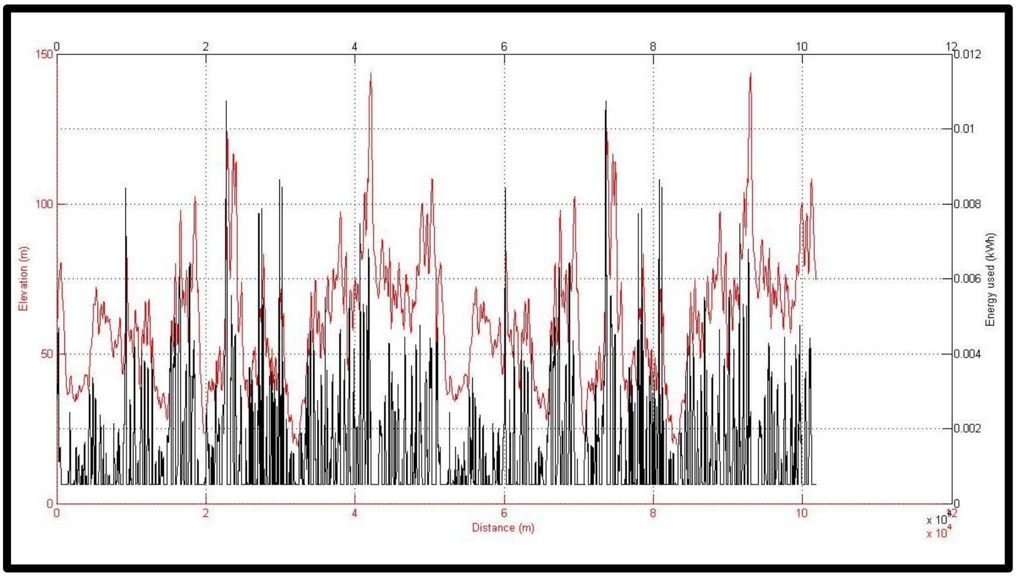


Figure 4.24: MATLAB Simulation Graph for Vehicle moving 100km on North-South Highway

Figure 4.22 and Figure 4.23 illustrates the elevation and energy consumption MATLAB simulated graphs respectively for vehicle moving 100km on the North-South Highway. The previous case study was done to analyse driving an electric vehicle on a main highway for a travelling distance of 50 kilometres. For this case study, a similar analysis was conducted but the travelling distance was increased to 100 kilometres. Figure 4.24 displays the result of a MATLAB simulation graph for an electric vehicle moving on a main highway in Malaysia, now for an even longer driving distance of 100 kilometres. From these results produced in Figure 4.24, it is also hard to analyse from point to point because of the density and large amount of data simulated by MATLAB, similar to the previous case study. However, the energy used by the electric vehicle throughout the 100 kilometres journey is also almost constant and even because there is a well balanced between uphills and downhills road conditions throughout the 100 kilometres driving journey.

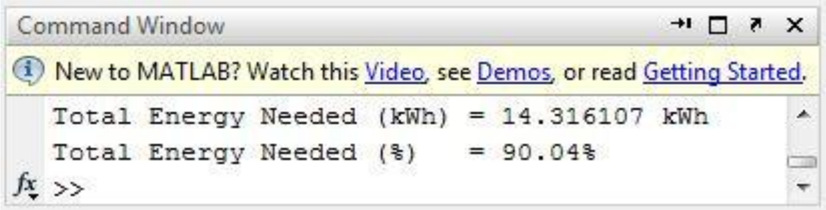


Figure 4.25: MATLAB Simulation Results for Vehicle moving 100km on North-South Highway

Figure 4.25 shows the simulation results that are obtained from MATLAB when the electric vehicle is moving on the North-South Highway for a distance of 100 kilometres. The results displayed are total energy needed in kWh (kilo Watt hours) and in % (percentage).

Distance estimation without road elevation calculations:

Y = 0.1325X,

where Y is energy used in kWh and X is distance travelled in kilometres

Y = 0.1325 (100)

Y = 13.25kWh of energy used or 83.33%.

Table 4.6: Calculation and Simulated Energy Used Results for Vehicle moving 100km on North-South Highway

Method Used	Energy Used (15.9kWh-100%)	
Distance estimation without road elevation	13.25kWh	83.33%
Distance estimation with road elevation (CPS)	14.316107kWh	90.04%

$$\begin{aligned}\text{Percentage difference} &= \left|\frac{\text{CPS - Conventional}}{\text{Conventional}}\right| \times 100\% \\ &= \left|\frac{90.04 - 83.33}{83.33}\right| \times 100\% \\ &= 8.05\%\end{aligned}$$

Table 4.6 displays the calculation and energy used results when the electric vehicle is moving on the North-South Highway for a distance of 100 kilometres. From the table, it is shown that the distance estimation with road elevation (CPS) consumes energy of 90.04% compared to distance estimation without road elevation at 83.33% where both results are also very similar to each other. This case study was conducted to be compared to the previous case study where the results were to simulate an electric vehicle driving on a 50 kilometres highway. The only difference was, in this case study, the simulated driving distance was increased to 100 kilometres. In this case study, the results produced for both the CPS and conventional distance estimation method do not produce much differences where the percentage difference between CPS and the conventional method is calculated to be 8.05%, which is a very low percentage difference and almost similar to the previous case study of 8.04%. Therefore to summarize, the results for both the 50 and 100 kilometres driving condition on a main highway are almost similar to each other and very consistent.

4.2.6 MATLAB Simulation for Vehicle Moving on a 50km Zero Gradient Road

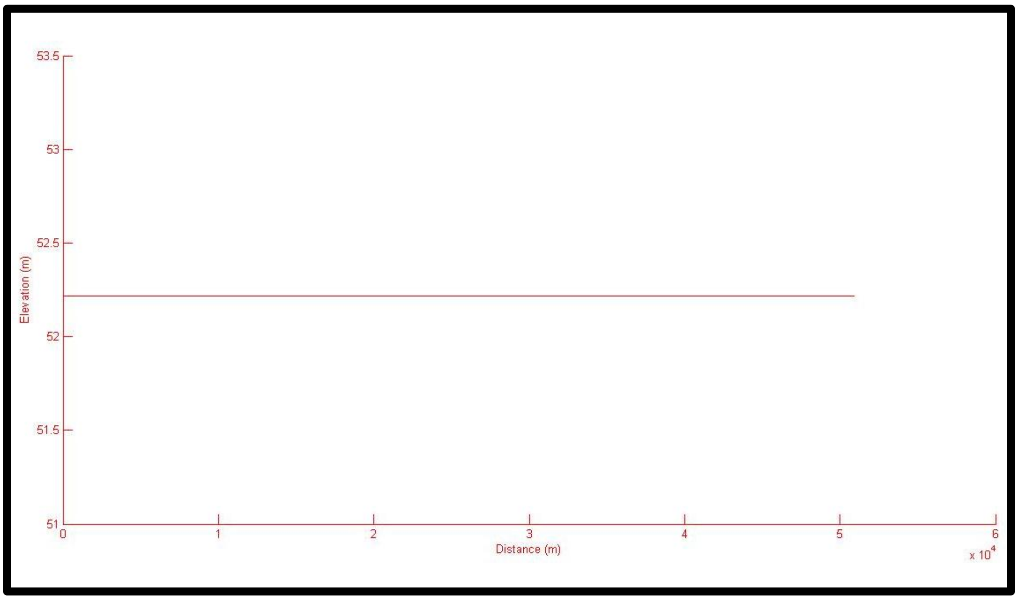


Figure 4.26: Elevation MATLAB Simulation for Vehicle moving on a 50km zero gradient road

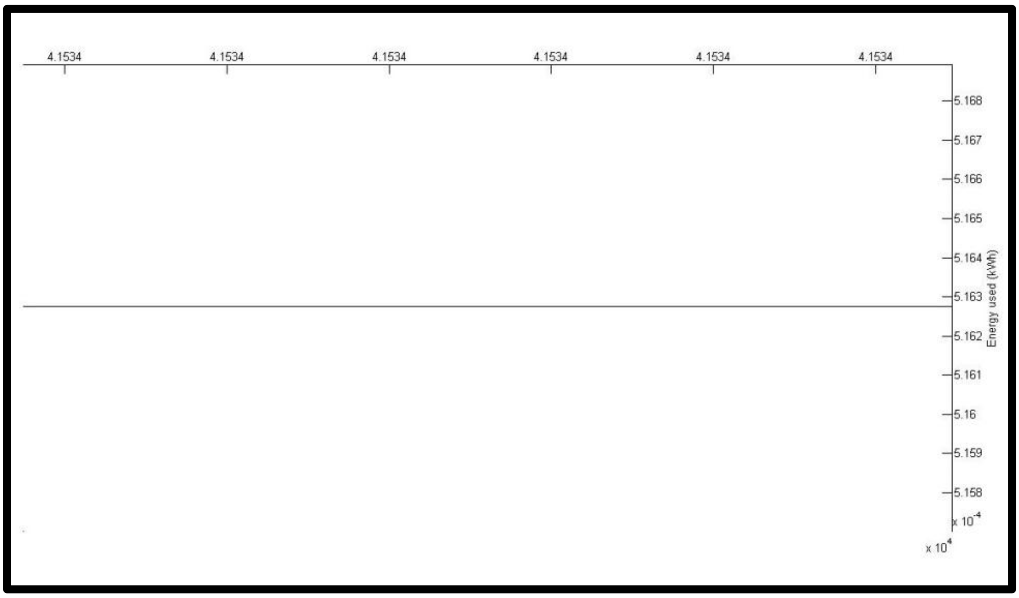


Figure 4.27: Energy Consumption MATLAB Simulation for Vehicle moving on a 50km zero gradient road

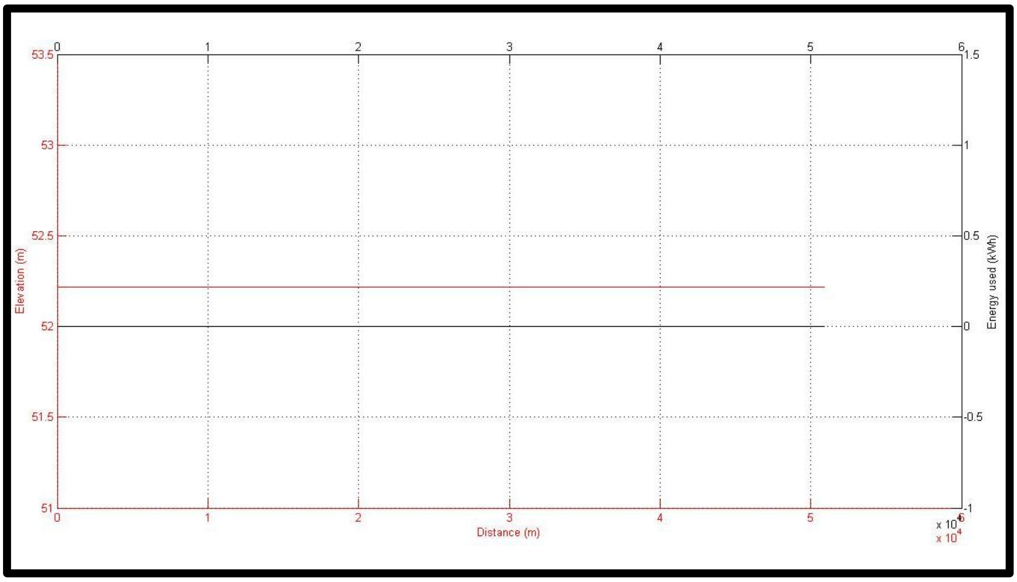


Figure 4.28: MATLAB Simulation Graph for Vehicle moving on a 50km zero gradient road

This case study is the MATLAB simulation for an electric vehicle moving on a 50 kilometres road with zero gradient and no slope angles. Figure 4.26 shows that this simulation has no elevation, and Figure 4.27 shows that this 50 kilometres journey has a constant energy consumption. From Figure 4.26, the electric vehicle is assumed to be travelling at a height of 52.2 meters from sea level. Figure 4.27 shows that the energy consumption is constant throughout the journey at close to 5.163 x 10^{-4} kWh. Figure 4.28 shows the complete MATLAB simulation graph for both the elevation and energy consumption profiles for an electric vehicle moving on a 50 kilometres zero gradient road.

Figure 4.29: MATLAB Simulation Results for Vehicle moving on a 50km zero gradient road

Figure 4.29 shows the simulation results that are obtained from MATLAB when the electric vehicle is moving on a 50 kilometres road with zero gradient and no slope angles. The results displayed are total energy needed in kWh (kilo Watt hours) and in % (percentage).

Distance estimation without road elevation calculations:

Y = 0.1325X,

where Y is energy used in kWh and X is distance travelled in kilometres

Y = 0.1325 (50)

Y = 6.625kWh of energy used or 41.67%.

Table 4.7: Calculation and Simulated Energy Used Results for Vehicle moving on a 50km zero gradient road

Method Used	Energy Used (15.9kWh-100%)	
Distance estimation without road elevation	6.625kWh	41.67%
Distance estimation with road elevation (CPS)	2.627331kWh	16.52%

$$\text{Percentage difference} = \left|\frac{\text{CPS - Conventional}}{\text{Conventional}}\right| \times 100\%$$
$$= \left|\frac{16.52 - 41.67}{41.67}\right| \times 100\%$$
$$= 60.36\%$$

Table 4.7 shows the calculation and simulated energy used results for the electric vehicle moving on a 50km zero gradient roads. This case study was conducted to observe and analyse the results for an electric vehicle moving on a road with zero gradient and no slope angles. In practical and real life, this type of road does not exist. It is nearly impossible to find a road with no slopes even on the highway unless an area is specifically designed for this experiment where the road is built in a circle and the electric vehicle is driven round that circle for a distance of 50 kilometres. Therefore, this experiment and case study was conducted to study the difference between the CPS and conventional distance estimation systems. From the results, the percentage difference between CPS and the conventional method is calculated to be 60.36%, which is a big percentage difference. Many may think that when the CPS does not takes into account the elevation and road slopes into the calculation, the simulated results will be the same as the conventional distance estimation method but this is not the case. There is an explanation for this. For the CPS simulation, the road load equation consist of four smaller equations; the linear acceleration equation, mav, the hill climbing equation, $mgv \sin \alpha$, the coefficient of rolling resistance equation, $Crr\ mgv \cos \alpha$, and the aerodynamic drag equation, $(\rho\ Cd\ A\ v^3)/2$. When the road gradient is zero, the hill climbing equation becomes zero. Since the vehicle is moving at a constant speed of 90km/h with no acceleration, the linear acceleration equation also becomes zero. And since the energy consumption of an electric vehicle is directly proportional to the road load power equation, the loss of the two smaller equations mentioned above results in a much lower energy used in this case study overall. A more detailed explanation for this case study can be found in the Discussion section of this research.

4.2.7 MATLAB Simulation for Vehicle Moving Uphill 500m

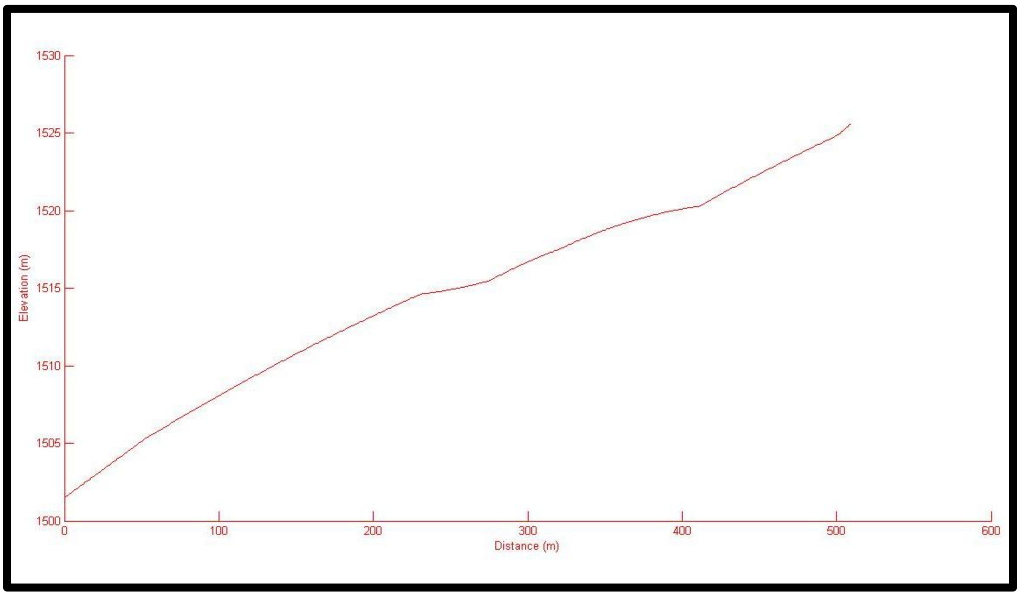


Figure 4.30: Elevation MATLAB Simulation for Vehicle moving uphill 500m

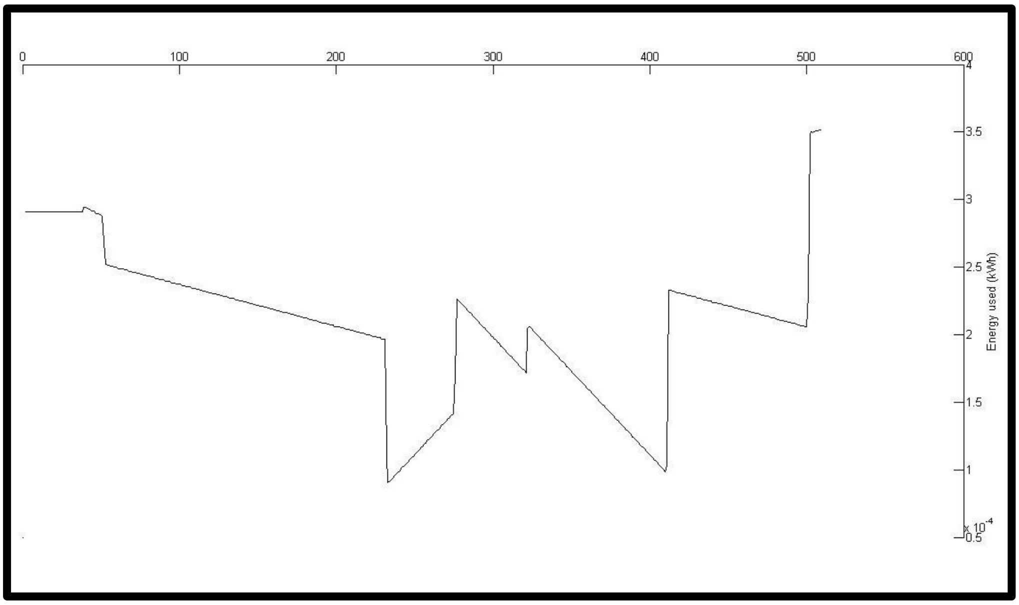


Figure 4.31: Energy Consumption MATLAB Simulation for Vehicle moving uphill 500m

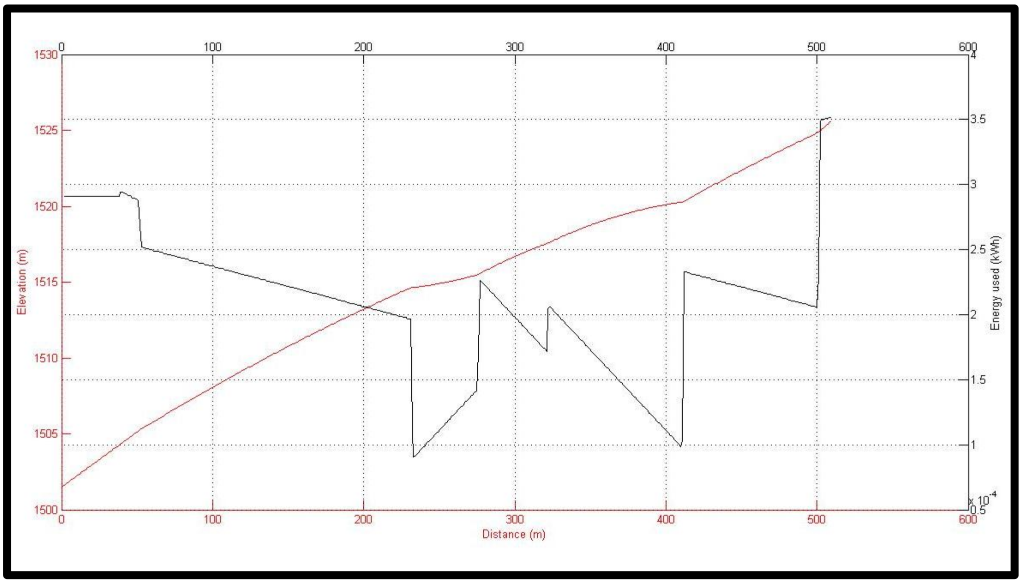


Figure 4.32: MATLAB Simulation Graph for Vehicle moving uphill 500m

Figure 4.30 and Figure 4.31 illustrates the elevation and energy consumption MATLAB simulated graphs respectively for vehicle moving uphill 500m. This case study was conducted to analyse the MATLAB simulation for an electric vehicle moving uphill for 500 meters. The reason the distance simulated is so short is to observe the difference in step changes in the energy consumption simulation as shown in Figure 4.31. With a smaller sample size, it is much easier to observe and analyse the small changes in the graph simulated when the electric vehicle moves on a shorter distance. It is the same concept as zooming into a graph of 500 meters of travelling distance instead of analysing a complete 50 or 100 kilometres journey. Figure 4.32 shows the MATLAB simulation results for both the elevation and corresponding energy consumption of an electric vehicle moving up a slope for 500 meters.

Figure 4.33: MATLAB Simulation Results for Vehicle moving uphill 500m

Figure 4.33 shows the simulation results that are obtained from MATLAB when the electric vehicle is moving up a hill slope for 500 meters. The results displayed are total energy needed in kWh (kilo Watt hours) and in % (percentage).

Distance estimation without road elevation calculations:

Y = 0.1325X,

where Y is energy used in kWh and X is distance travelled in kilometres

Y = 0.1325 (0.5)

Y = 0.06625kWh of energy used or 0.42%.

Table 4.8: Calculation and Simulated Energy Used Results for Vehicle moving uphill 500m

Method Used	Energy Used (15.9kWh-100%)	
Distance estimation without road elevation	0.06625kWh	0.42%
Distance estimation with road elevation (CPS)	0.105467kWh	0.66%

$$\text{Percentage difference} = \left|\frac{\text{CPS - Conventional}}{\text{Conventional}}\right| \times 100\%$$
$$= \left|\frac{0.66 - 0.42}{0.42}\right| \times 100\%$$
$$= 57.14\%$$

Table 4.8 summarises the calculation and simulated energy used results for the vehicle moving uphill 500m. This case study was conducted to study a MATLAB simulated results for a smaller travelling distance of an electric vehicle and therefore, a smaller sample size of 500 meters was taken. In all the MATLAB simulations, the distance and elevation information are extracted from Google Earth's elevation data. In Figures 4.31 and 4.32, some would question, why the energy consumption graph is not a smooth and continuous graph but there is an explanation for this.

The reason is because the distance information extracted from Google Earth's elevation profile is done in the steps of every 10 meters. This means that the sample size collected for the distance data extracted into the Excel spread sheet is also done for every 10 meters starting from 0 meter at the start of a journey. Therefore, the extracted information was used in the MATLAB simulation and the results are shown in Figure 4.32. If the distance and elevation information are extracted in a continuous form, the MATLAB simulated graph in Figure 4.32 will also be a continuous curve.

This continuous data can be done as a future implementation by using some differential and integral equations. Moreover from Figure 4.31, it can be observed that the energy consumption graph changes from 1 to 3.5 x 10^{-4} kWh which is very small step fluctuation which will not affect much the accuracy of the results simulated. Of course, however the smaller the step change and sample size, the more accurate the MATLAB simulated results will be.

From the results, the percentage difference between CPS and the conventional method is calculated to be 57.14%, which is a big percentage difference due to the short travelling distance of 500 meters only. In this case, the longer the travelling distance, the more accurate the percentage difference calculated between CPS and the conventional distance estimation method. This does not means that the CPS is not a reliable source for distance estimation for an electric vehicle or it is not precise, it only means that a larger set of data samples are needed to provide a more accurate comparison to the conventional distance estimation method. This is main reason why the 50 and 100 kilometres travelling distance case studies are conducted is to compare the accuracy of results simulated with a shorter travelling distance case studies.

4.2.8 MATLAB Simulation for Vehicle Moving 15.27km from UTAR to Technology Park Malaysia (Route 1)

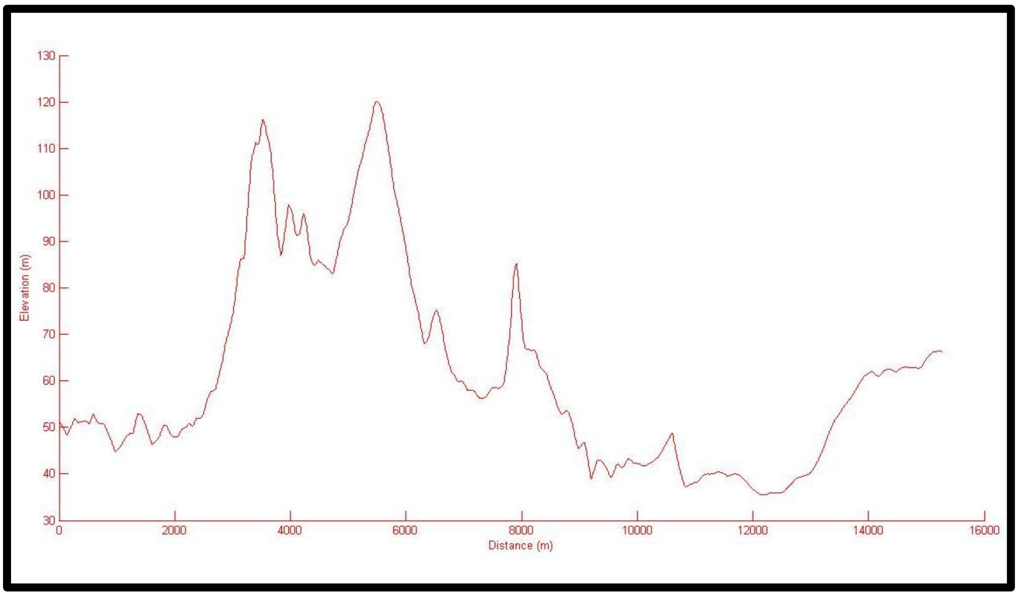


Figure 4.34: Elevation MATLAB Simulation for Vehicle moving 15.27km from UTAR to Technology Park Malaysia (Route 1)

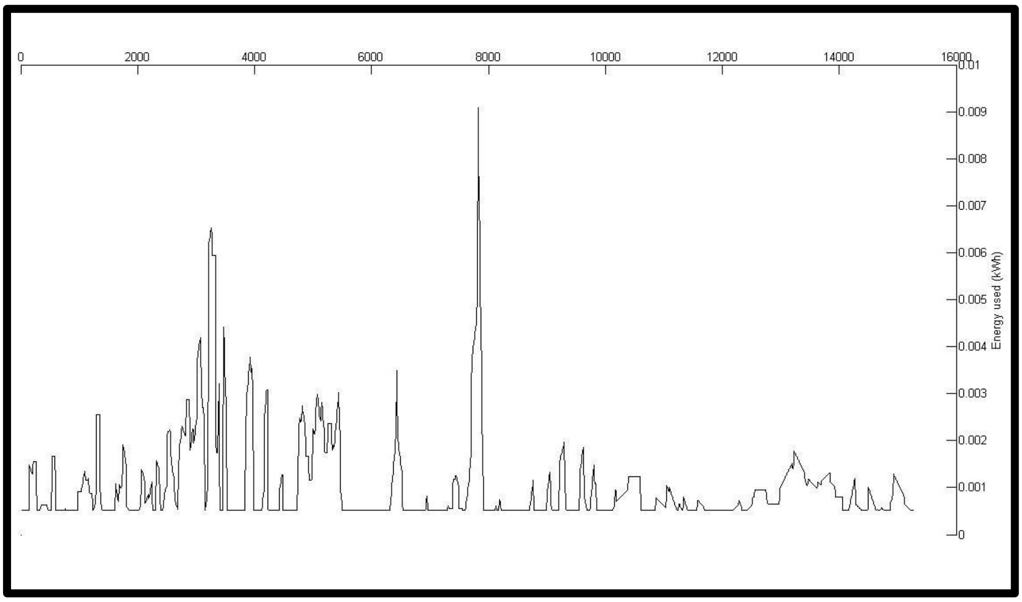


Figure 4.35: Energy Consumption MATLAB Simulation for Vehicle moving 15.27km from UTAR to Technology Park Malaysia (Route 1)

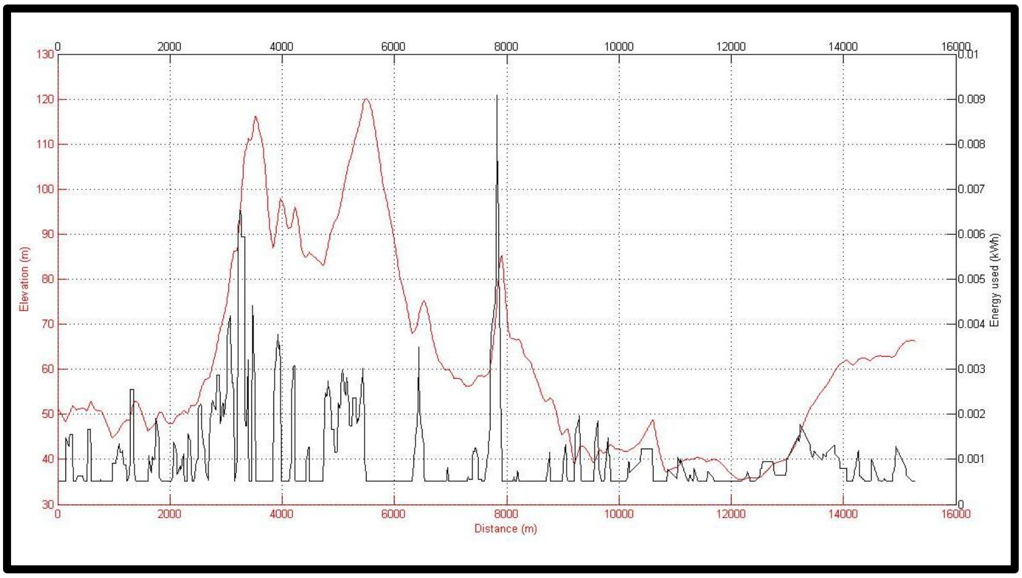


Figure 4.36: MATLAB Simulation Graph for Vehicle moving 15.27km from UTAR to Technology Park Malaysia (Route 1)

Figure 4.34 and Figure 4.35 illustrates the elevation and energy consumption MATLAB simulated graphs respectively for vehicle moving 15.27km from UTAR Setapak to Technology Park Malaysia using the first driving route. This was an additional case study that was done for a travelling distance from University Tunku Abdul Rahman(UTAR) from Setapak to Technology Park Malaysia in Bukit Jalil for a distance of 15.27 kilometres. This is a practical and real life case study but it was done by driving an injection combustion engine(ICE) vehicle, not an electric vehicle. Therefore, only the distance and elevation information extracted are practical, the MATLAB simulations are still simulated using standard specifications from an electric vehicle. In Figure 4.35, there are only two notable spikes in energy consumption around 3000 and 8000 meters where the corresponding elevation can be seen in Figure 4.36. Apart from the two spikes, the rest of the graph shows an almost constant fluctuation in energy consumption.

Figure 4.37: MATLAB Simulation Results for Vehicle moving 15.27km from UTAR to Technology Park Malaysia (Route 1)

Figure 4.37 shows the simulation results that are obtained from MATLAB when the electric vehicle is moving 15.27 kilometres from UTAR Setapak to Technology Park Malaysia in Bukit Jalil. The results displayed are total energy needed in kWh (kilo Watt hours) and in % (percentage).

Distance estimation without road elevation calculations:

Y = 0.1325X,

where Y is energy used in kWh and X is distance travelled in kilometres

Y = 0.1325 (15.27)

Y = 2.02328kWh of energy used or 12.73%.

Table 4.9: Calculation and Simulated Energy Used Results for Vehicle moving 15.27km from UTAR to Technology Park Malaysia (Route 1)

Method Used	Energy Used (15.9kWh-100%)	
Distance estimation without road elevation	2.023275kWh	12.73%
Distance estimation with road elevation (CPS)	1.557054kWh	9.79%

$$\text{Percentage difference} = \left|\frac{\text{CPS - Conventional}}{\text{Conventional}}\right| \times 100\%$$
$$= \left|\frac{9.79 - 12.73}{12.73}\right| \times 100\%$$
$$= 23.10\%$$

Table 4.9 summarises the calculation and simulated energy used results for the vehicle moving 15.27km from UTAR Setapak to Technology Park Malaysia using the first driving route. This case study was an additional research done from UTAR Setapak to Technology Park Malaysia due to the 100 Best Technopreneur Competition 2012 event held there, the 4th Technopreneurship & Innovation Symposium & Exhibition (TISE) 2012 in October 2012 where the author presented the Contour Positioning System (CPS) research at the event. Therefore simultaneously, the distance and elevation information was extracted to be simulated into MATLAB. The journey was travelled through a highway which results in the simulation shown in Figure 4.36. From the results, the percentage difference between CPS and the conventional method is calculated to be 23.10%, which is an acceptable percentage which shows the difference when hilly slopes are taken into account in the distance estimation calculations.

4.2.9 MATLAB Simulation for Vehicle Moving 15.58km from UTAR to Technology Park Malaysia (Route 2)

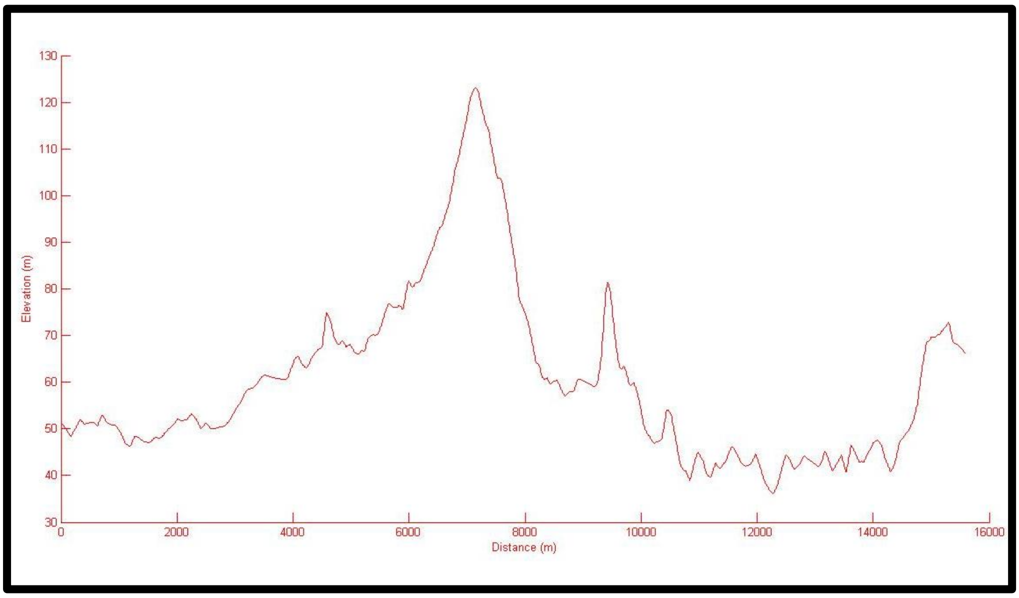


Figure 4.38: Elevation MATLAB Simulation for Vehicle moving 15.58km from UTAR to Technology Park Malaysia (Route 2)

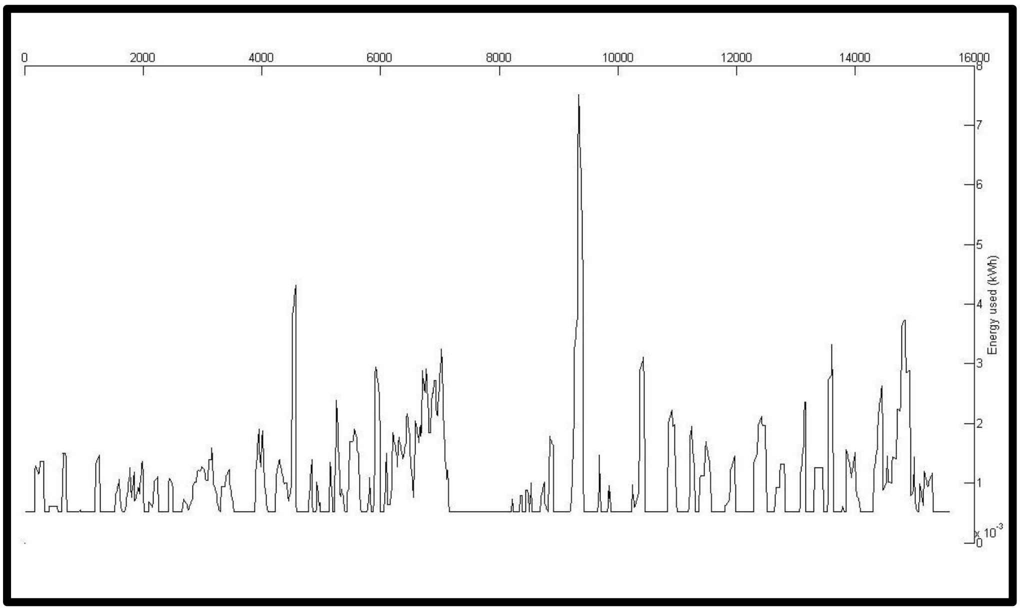


Figure 4.39: Energy Consumption MATLAB Simulation for Vehicle moving 15.58km from UTAR to Technology Park Malaysia (Route 2)

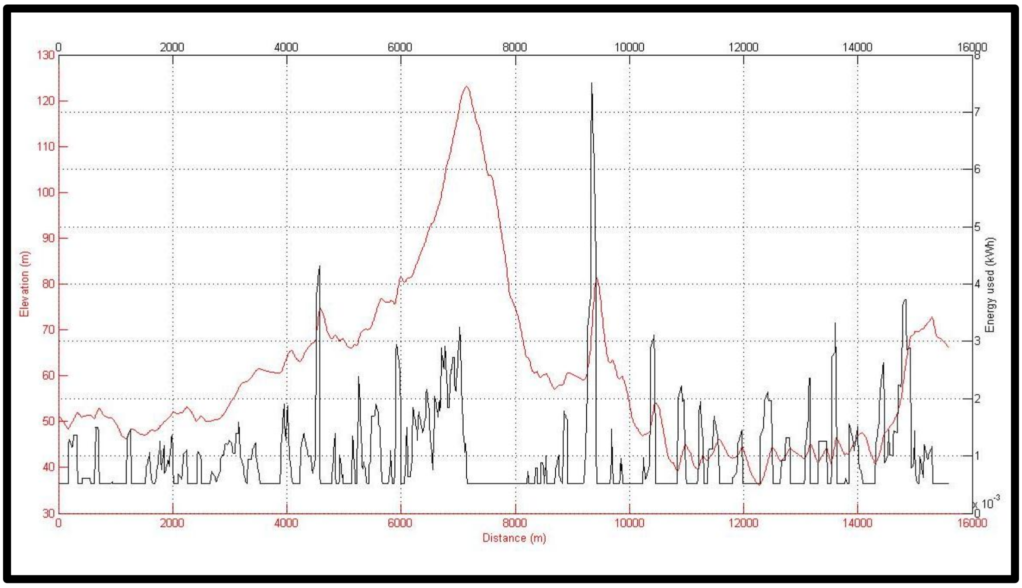


Figure 4.40: MATLAB Simulation Graph for Vehicle moving 15.58km from UTAR to Technology Park Malaysia (Route 2)

Figure 4.38 and Figure 4.39 illustrates the elevation and energy consumption MATLAB simulated graphs respectively for vehicle moving 15.58km from UTAR Setapak to Technology Park Malaysia using the second driving route. This was also an additional case study that was done for a travelling distance from University Tunku Abdul Rahman(UTAR) from Setapak to Technology Park Malaysia in Bukit Jalil but for a different route and distance of 15.58 kilometres. This is also a practical and real life case study that was done by driving an injection combustion engine(ICE) vehicle. Therefore, the distance and elevation information extracted are practical and the MATLAB simulations are simulated using general specifications of an electric vehicle. In Figure 4.39, there is only one notable spike in energy consumption around 9000 meters where the corresponding elevation can be seen in Figure 4.40. In Figure 4.40, there is also an obvious elevation difference at around 7000 meters but the corresponding energy consumption did not show much of a spike because the increase in elevation was gradual but up to a higher position. Apart from that one spike, the rest of the graph shows an almost constant change in energy consumption.

Figure 4.41: MATLAB Simulation Results for Vehicle moving 15.58km from UTAR to Technology Park Malaysia (Route 2)

Figure 4.41 shows the simulation results that are obtained from MATLAB when the electric vehicle is moving 15.58 kilometres from UTAR Setapak to Technology Park Malaysia in Bukit Jalil. The results displayed are total energy needed in kWh (kilo Watt hours) and in % (percentage).

Distance estimation without road elevation calculations:

Y = 0.1325X,

where Y is energy used in kWh and X is distance travelled in kilometres

Y = 0.1325 (15.58)

Y = 2.06435kWh of energy used or 12.98%.

Table 4.10: Calculation and Simulated Energy Used Results for Vehicle moving 15.58km from UTAR to Technology Park Malaysia (Route 2)

Method Used	Energy Used (15.9kWh-100%)	
Distance estimation without road elevation	2.06435kWh	12.98%
Distance estimation with road elevation (CPS)	1.525460kWh	9.59%

$$\begin{aligned} \text{Percentage difference} &= \left| \frac{\text{CPS - Conventional}}{\text{Conventional}} \right| \times 100\% \\ &= \left| \frac{9.59 - 12.98}{12.98} \right| \times 100\% \\ &= 26.12\% \end{aligned}$$

Table 4.10 summarises the calculation and simulated energy used results for the vehicle moving 15.58km from UTAR Setapak to Technology Park Malaysia using the second driving route. This case study was also an additional research done from UTAR Setapak to Technology Park Malaysia on the second day of the 4th Technopreneurship & Innovation Symposium & Exhibition (TISE) 2012. Therefore simultaneously, the distance and elevation information was extracted to be simulated into MATLAB. The only difference compared to the previous case study, 4.2.8, was the route to Technology Park Malaysia was different because this journey was done on the second day of the event. The journey was travelled through a different highway which results in the simulation shown in Figure 4.40. The distance travelled is also slightly longer at 15.58 kilometres compared to the first day journey of 15.27

kilometres. From the results, the percentage difference between CPS and the conventional method is calculated to be 26.12%, which is also an acceptable percentage which shows the difference when road gradients are taken into account in the distance estimation calculations. This result also does not differ much from the previous case study's percentage difference of 23.10% which shows that the CPS simulated results are consistent from one to the other.

4.3 Results Summary

Table 4.11: The Percentage Difference for Each and Every Case Study Driving Profiles

Case Study Driving Profiles	Percentage Difference (%)
1. Vehicle moving uphill 5km	28.30
2. Vehicle moving downhill 5km	- 31.18
3. Three 5km hills	85.37
4. North-South Highway 5km	- 21.82
5. North-South Highway 50km	8.04
6. North-South Highway 100km	8.05
7. Zero gradient road 50km	- 60.36
8. Vehicle moving uphill 500m	57.14
9. UTAR to TPM 15.27km (Route 1)	- 23.10
10. UTAR to TPM 15.58km (Route 2)	- 26.12

Table 4.12: The Percentage Summary Segmented into Different Driving Profiles

Driving Profiles	Number of samples	Percentage Range
Zero Gradient Travelling	**1**	**-60.36%**
Downhill Travelling	**1**	**-31.18%**
Highway Travelling	**5**	**-26.12% to 8.05%**
Uphill Travelling	**3**	**28.30% to 85.37%**

4.4 Discussions

From the results summary above, it can be seen that when the electric vehicle is moving uphill in driving profiles 1, 3, and 8, the percentage of energy consumption simulation is significantly higher compared to conventional range prediction techniques ranging from 28.30% to 85.67%. Case study 4.2.2 with the driving profile number 3 in Table 4.11 registers a much higher energy consumption at 85.67% compared to other uphill case studies mainly because there are three uphill driving within that 5 kilometres journey which are very steep. Therefore, this will result in higher energy consumption from the battery pack of the electric vehicle. This was the main objective of the research where driving on hilly terrains and slopes will consume a significantly much more energy from the battery pack.

For a downhill driving profile shown in 2, the percentage of energy consumption simulation is significantly lower compared to conventional range prediction techniques at -31.18%. This means that the electric vehicle consumes a significantly less amount of energy from the battery pack compared to what the conventional range prediction method estimates.

For highways and normal roads in driving profile 4, 5, 6, 9, and 10, the percentage of energy consumption simulation fluctuates between positives and negatives ranging from -26.12% to +8.05%. This shows that the energy consumption for highway and normal roads depend on the amount of uphill and downhill road conditions where if there are more uphills, the energy consumption will be higher on average and vice versa. For the 50km and 100km North-South Highway driving profiles, the energy consumption simulation does not vary much from the conventional results at 8.04% and 8.05% respectively. This means that for a longer distance driving, the amount of uphill and downhill road conditions average up in total resulting in almost similar energy consumption with the conventional method. This also shows that the conventional range prediction method is more suitable for estimating distance for long range driving especially on highways and normal roads.

For the zero gradient road of 50km, the results shown by the CPS range prediction simulation is very interesting and different from the conventional range prediction technique. As usual, the conventional method predicts the energy consumption of the vehicle the same way for any given road condition, either its uphill, downhill, highway, straight road or zero gradient road driving profile, the range prediction method is based on a ratio basis between the maximum battery energy capacity in kWh to the maximum expected driving distance for a fully charged battery pack in kilometres. Therefore, the energy consumption for the conventional method is 41.67% in this case.

On the other hand for the CPS range prediction technique, it estimates the energy consumption of the electric vehicle based on different road contours, elevations and slopes which consumes a very different amount of battery energy. Therefore for the zero gradient road of 50km case study, the CPS range prediction simulates a much lower energy consumption of only

16.52%. This is the main reason why the percentage difference between the two results is large at 60.36% which means a difference of more than half of the CPS energy consumption.

To explain the huge difference in results between both the range prediction techniques; when the electric vehicle is moving at a constant speed of 90km/h on a zero gradient road, there is no uphill or downhill resistance means that there is no fluctuation in the energy consumption. At the same time, there is also no acceleration needed because the 50km journey is cruising at a constant speed of 90km/h. Therefore, there are no extra battery energy needed for the electric vehicle to accelerate or decelerate resulting in a much lower energy consumption overall. The difference in results can also be explained from the road load equation below:

$$P = mav + mgv\sin\alpha + C_{RR}mgv\cos\alpha + \frac{1}{2}\rho C_D A v^3 \quad (5)$$

When the road gradient is zero, sin 0 in the hill climbing power equation makes $mgv \sin \alpha = 0$ resulting in one less equation in the road load power equation calculations. And since the energy consumption of an electric vehicle is directly proportional to the road load traction power as below,

Energy used (kWh) = Traction power (kW) x Time taken (h) (8)

the loss of the hill climbing power equation, $mgv \sin \alpha$ will result in a much lower energy consumption overall.

On the other hand, for the coefficient of rolling resistance power equation, $Crr\ mgv\ cos\ \alpha$, the value of cos 1 = 1 will provide the maximum power in this equation. However, the coefficient of rolling resistance value is Crr = 0.005, which is very small and almost negligible, therefore the power consumption for this equation in the road load power equation will not have much effect on the overall power calculations.

To conclude and summarize everything for the zero gradient road of 50km case study, the acceleration and hill climbing equation in the road load equation is zero while the coefficient of road load equation does not have much impact on the overall power consumption calculations, therefore the CPS range prediction simulation produces a much more lower power consumption results. These results are more accurate to the real world energy consumption results compared to the conventional range prediction technique which only calculates the ratio between distance travelled in kilometres and the amount of battery energy used in percentage and kWh. The lower energy consumption and range prediction makes more sense and is closer to the real energy consumption of the electric vehicle based on the simulation conducted. For the 50km zero gradient road simulation, there is no practical way to test the simulation and results in a real world environment because in reality, a zero gradient road does not exist for a long distance of 50km. Therefore this simulation was done for the sake of comparison with the conventional range prediction technique and for data analysis purpose.

To summarize it all, the conventional distance estimation method is deduced based on the average driving profile of uphill's, downhill's, highways, cities, and straight roads as shown in Figure 3.12 where it is a good example. This graph is the results of a hybrid electric vehicle driver who drove his vehicle for 45 days on different driving profiles and terrains, each day with different distances and he calculated the average fuel consumption for his vehicle in kilometres per litre for each day. At the end of the 45 days, he summarizes the complete graph in blue and plotted a linear straight line graph where it is the average fuel consumption of the whole vehicle. Therefore, it is safe to say that the conventional distance estimation method is based on the average of all the different driving profiles and terrains where it is similar to a long distance highway driving profile. This will be the reference point where the CPS will be compared to and the simulations done prove that the CPS can be used to estimate the distance of different driving profiles accurately.

From the results summary, the simulations done for highway travelling differ from -26.12% to 8.05% which is almost evenly distributed around the reference point of the conventional distance estimation method. For uphill travelling simulations, CPS shows an increase in energy consumption of around 28.30% to 85.37%. Whereas for downhill travelling, CPS shows that it will consume -31.18% less energy compared to the conventional distance estimation method. For the zero gradients travelling, the energy consumption is significantly lower at -60.36% because there is no acceleration or deceleration where the vehicle can be assumed to be cruising at a constant velocity.

4.5 CPS Graphical User Interface (GUI)

The CPS has a Graphical User Interface (GUI) for the user to navigate all the functions available in the system (Wayne, 2011). All the calculations and simulations are done in the background of this interface. Figure 4.42 shows the CPS GUI of the system.

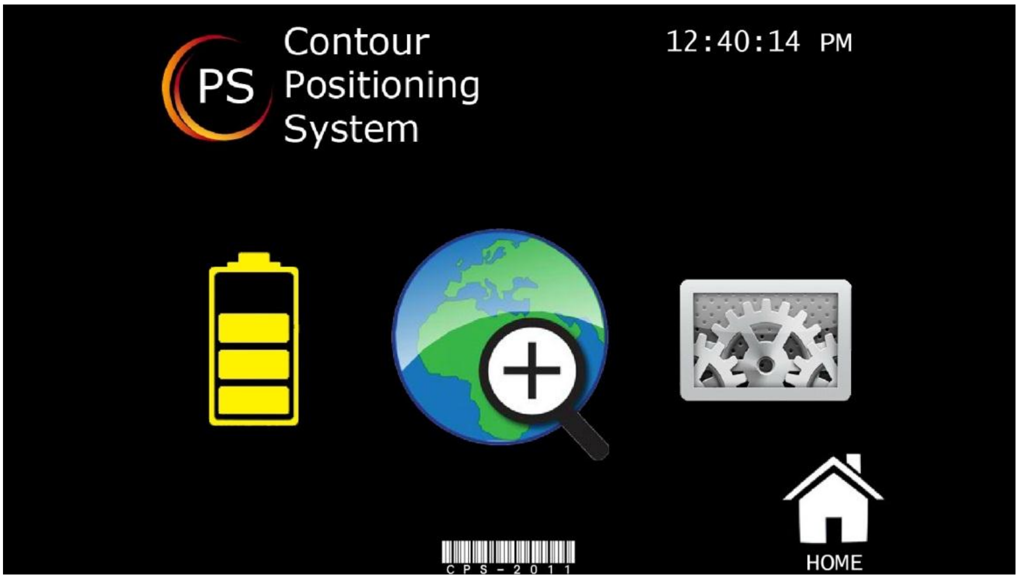


Figure 4.42: CPS GUI

The CPS GUI has three main functions; the battery icon on the left, the navigation icon in the middle and the settings icon on the right. Figure 4.43 shows the features available in the battery icon.

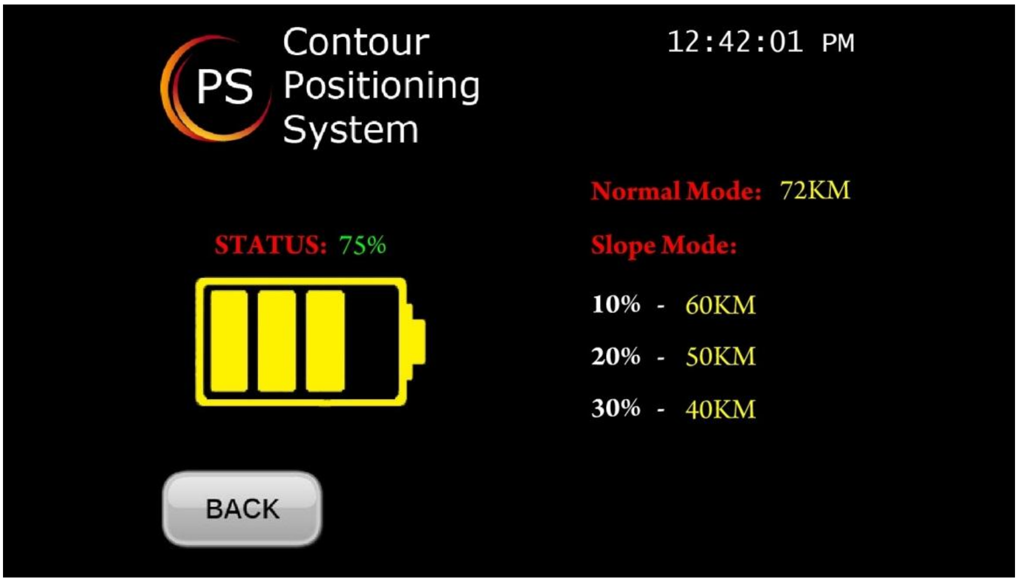


Figure 4.43: Battery Icon GUI

Under the battery icon, the user can monitor the amount of battery energy left and the travelling distance available based on different slope conditions. The normal mode estimation is based on cruising at 90km/h on a straight road highway and the slope mode is based on the vehicle moving uphill on different slope steepness. Figure 4.44 shows the features available in the navigation icon.

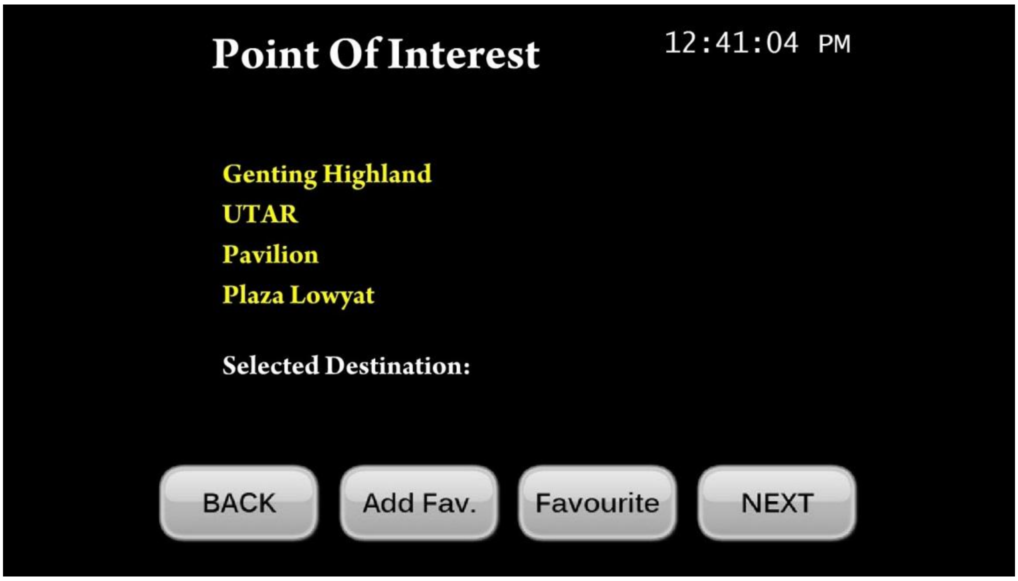


Figure 4.44: Navigation Icon GUI

Under the navigation icon is where the main function of the CPS takes place. After, the user type in the destination of their journey and select next, CPS will calculate the estimated distance in the background and display them to the user as shown in Figure 4.45. Users can also save selected point of interest into their favourite's icon.

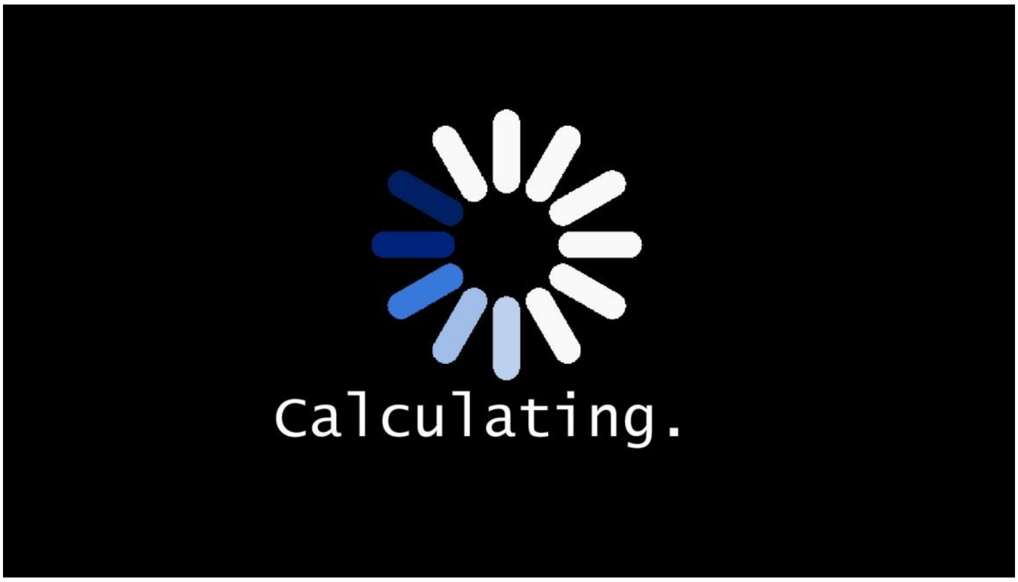


Figure 4.45: CPS Calculating the Result for the Selected Destination

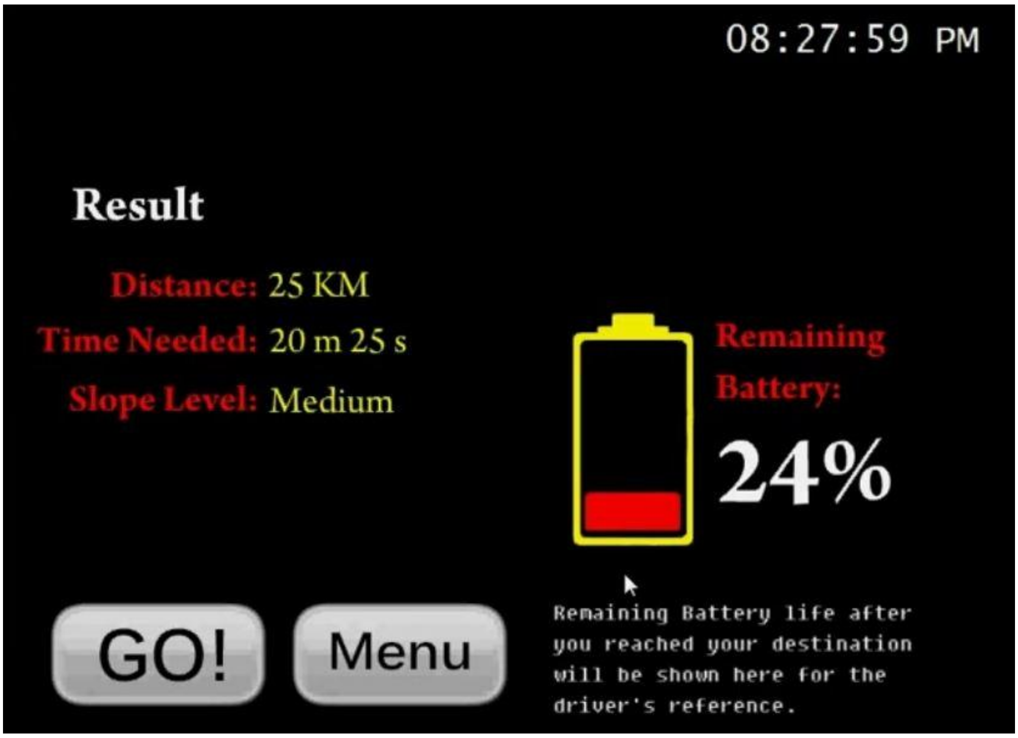


Figure 4.46: CPS Estimated Distance Results

Figure 4.46 shows the estimated distance simulation results using the CPS. The CPS results will display three main functions; estimated distance of the journey, time needed and the remaining battery life after reaching the destination. When the user is ready and select the GO icon, Figure 4.47 will be displayed.

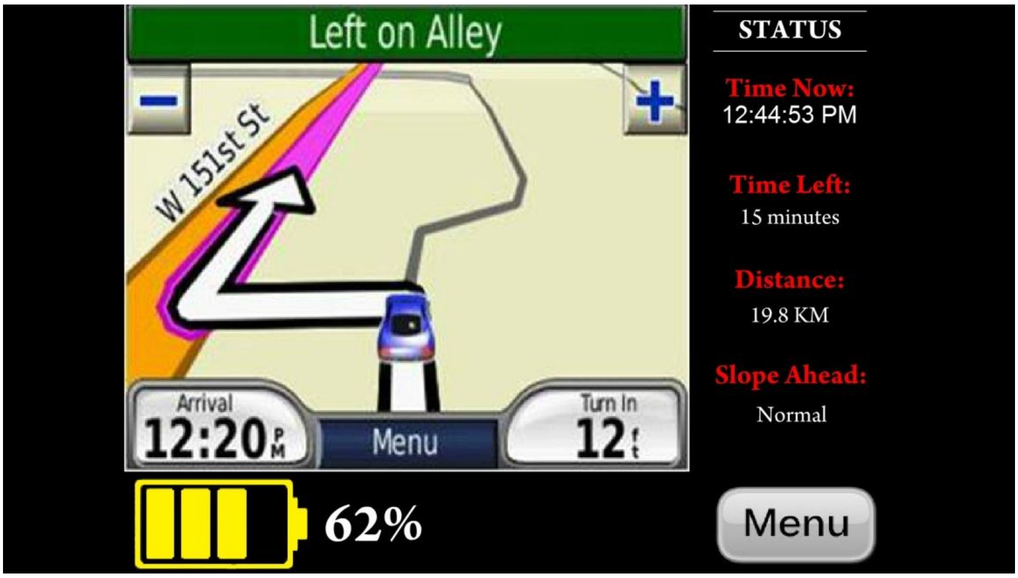


Figure 4.47: CPS Vehicle navigation GUI

The CPS vehicle navigation GUI is where a standard GPS navigation system will be embedded. This feature is achieved by collaborating with a local GPS company.

Apart from the CPS GUI, the main program GUI also has other features embedded as shown in Figure 4.48.

Figure 4.48: Main Program GUI

The main program has several functions such as battery management system where users can monitor the performance of the battery in terms of voltage, current and temperature, car infotainment where users can listen to music, radio, watch movies and surf the internet, the car cooling system where all the temperature sensors of the vehicle can be monitored, phone functions where a smartphone can be connected to the vehicle wirelessly via Bluetooth to answer calls hands-free, the CPS GUI and GUI preference settings where some of the basic GUI settings such as software updates, background wallpaper, volume and others can be changed.

CHAPTER 5

CONCLUSION

5.1 Summary

Electric vehicle technology is now in its third century of development and is likely to advance rapidly in the coming years. Therefore research in this area is definitely relevant especially if it involves solving a problem that current users are facing.

The CPS research was proposed and created to solve problems from conventional distance estimation system where the latter could not tell the difference in energy consumption between driving uphill and on a 0° normal road. If an electric vehicle moves up a hill, the current distance and battery capacity prediction is not accurate and will predict with a high percentage of error. This is important to avoid electric vehicles from being stranded in the middle of a road because the conventional system predicted a farther distance compared to the actual situation.

The work done during this research was to extract the elevation profile information from Google Earth, use the information to simulate the energy consumption of an electric vehicle when moving on the road especially uphill and compare the results with the conventional distance estimation method.

The achievement was a significant difference in energy consumed between the two methods where the CPS method records an average of 20-30% extra energy consumed compared to the conventional method when an electric vehicle moves uphill. Therefore, the objectives of this research have been accomplished where a novel and more accurate distance estimation system for electric vehicles has been proposed where it takes into account of the road elevation information which consumes additional amount of electrical energy from the battery pack.

Efforts are also already underway to integrate the CPS into current electric cars and also the current GPS systems available in the market. Moreover, another advantage that the CPS has is it can be implemented and suited into any electric vehicle system as long as the specifications and technical data are provided by the automotive manufacturers.

5.2 Proposed Future Improvements

The regenerative braking feature of the Proton Saga EV can regenerate approximately 5% of consumed energy back to the lithium-ion battery pack. However, this 5% of regenerative energy is not included into the CPS calculations to provide a small safety buffer into the CPS distance estimation. For example, when the fuel meter of an engine car hits the ‘Empty’ mark, it will still be able to travel an additional 30 to 40 miles even after the fuel’s ‘E’ light illuminates (Davis, 2012).

Another method that has been considered and will be employed to improve the CPS is by using self-learning algorithms. This method will be used when certain specifications and technical data are unavailable or to reroute to a new driving direction when there is a traffic jam using Google Maps real-time traffic data (David, 2007).

The CPS assumes connection with Google Earth database within the car but it might not be possible all the time. Therefore to solve this problem, the solution provided was to search for the desired destination and save it when the vehicle is at home or has connection to the internet before starting the journey. This is because the CPS is capable of saving the selected point of interest into the 'favourites' folder as shown in Figure 4.44 and the user can use it over and over again. Apart from that, the data acquisition running under the multiple processor platforms are fast and only needed to be done before starting the journey. It is not necessary for the CPS to be online all the time. Another alternative would be to connect the CPS with a standard navigation system which contains elevation information compared to extracting from Google Earth's elevation profile which requires an internet connection.

5.2.1 Dynamic CPS

The CPS research was done based on the concept of static CPS where all the data and information obtained and used in the MATLAB programming calculation and simulations are fixed. For example, the distance and elevation obtained from Google Earth elevation profile, the technical and specifications data obtained from the electric vehicle such as mass, aerodynamic drag, coefficient of rolling resistance, frontal area, and even the air density, are all fixed and non-changing variables used in the programming and simulation process of the CPS.

Therefore, the proposed future improvement to enhance the range prediction technique of the CPS can be done by implementing a newer concept called, *Dynamic CPS*. Dynamic CPS is the utilization of random and changing variables into the range prediction simulation such as users driving behaviour, recognizing previous driving pattern for the same route drove earlier, recognizing different car load, feeding current traffic condition information into the simulation, implementing artificial intelligence techniques, self-learning algorithms, extra energy produced by regenerative braking and many more. The method used to implement this new technique can be by using MATLAB because the programming and simulations are comprehensive enough to embed all the new features mentioned above into the CPS. By using this novel method in the future, the range prediction technique of the CPS can be even more precise and accurate when estimating the distance of a journey travelled.

A more simplified distinction between Static and Dynamic CPS can be explained in Table 5.1:

Table 5.1: Static CPS versus Dynamic CPS

Static CPS	Dynamic CPS
data and information obtained are fixed, non-changing variables are used	data and information obtained are random, variables are changing and feedback during real-time
distance and elevation obtained from Google Earth elevation profile	users driving behaviour and driving pattern recognition
technical and specifications data obtained from the electric vehicle such as mass, aerodynamic drag, coefficient of rolling resistance, frontal area	extra energy produced by regenerative braking
environmental factor such as air density	current traffic condition
	artificial intelligence techniques
	self-learning algorithms
	recognizing different car load

5.2.2 Regenerative Braking

A regenerative brake is an energy recovery mechanism which slows a vehicle or object down by converting its kinetic energy into another form, which can be either used immediately or stored until needed. This contrasts with conventional braking systems, where the excess kinetic energy is converted to heat by friction in the brake linings and therefore wasted (Regenerative Brake, 2012).

The most common form of regenerative brake involves using an electric motor as an electric generator. In electric railways the generated electricity is fed back into the supply system, whereas in battery electric and hybrid electric vehicles, the energy is stored chemically in a battery, electrically in a bank of capacitors, or mechanically in a rotating flywheel. Hydraulic hybrid vehicles use hydraulic motors and store energy in form of compressed air.

Using regenerative braking, a feature which is present on many hybrid electric vehicles, approximately 20% of the energy usually lost in the brakes is recovered to recharge the batteries (Electric Car, 2012). Electric motors often achieve 90% energy conversion efficiency over the full range of speeds and power output and can be precisely controlled. They can also be combined with regenerative braking systems that have the ability to convert movement energy back into stored electricity. This can be used to reduce the wear on brake systems (and consequent brake pad dust) and reduce the total energy requirement of a trip. Regenerative braking is especially effective for start-and-stop city use (Electric Vehicle, 2012).

Vehicles driven by electric motors use the motor as a generator when using regenerative braking: it is operated as a generator during braking and its output is supplied to an electrical load; the transfer of energy to the load provides the braking effect.

Regenerative braking is used on hybrid gas/electric automobiles to recoup some of the energy lost during stopping. This energy is saved in a storage battery and used later to power the motor whenever the car is in electric mode.

Many modern hybrid and electric vehicles use this technique to extend the range of the battery pack. Examples include the Toyota Prius, Honda Insight, Vectrix electric maxi-scooter, Tesla Roadster, Nissan Leaf, and the Chevrolet Volt.

5.2.3 Traffic Condition

Different types of traffic condition will also affect the precision of the current conventional distance estimation system in an electric vehicle severely. For example, getting stuck in a traffic jam and driving smoothly at a constant speed at two different times on the same driving path and distance will consume different amount of energy from the battery pack. Furthermore, driving on the same path and distance at different times in a day will produce different traffic conditions depending on the peak(8am and 6pm) or off-peak driving periods in a day. Even driving on the same path and distance at the same time every different day will have different amount of energy consumption and this factor will be affected more severely if an accident occurred on the road side (Keeratiwintakorn et al., 2008).

Therefore, unpredictable traffic conditions can happen at any time and any day, and a good distance estimation system should be able to include this consideration into their system. A proposed method to solve this problem is by integrating the Google Maps real-time traffic data and transit information into current distance estimation system for more accurate precision.

Google Malaysia has introduced three major enhancements to Google Maps which will allow Malaysian commuters to better plan their journeys and to look up real time information – the enhancements consist of two new layers called Traffic and Transit as well as a Bahasa Malaysia interface.

Traffic, as its description suggests, provides data on real time road congestion right on the map. By turning on the Traffic layer on Maps, users can quickly see whether roads are congested or flowing freely, all based on colour coding; red for choc-a-bloc, yellow for slow moving, and green for smooth flowing. Drivers that are fairly well-versed with the roads can also use the information to plan alternative routes to their destination.

As for Transit, this one provides information on travel via the Malaysian public transportation system on Maps. Now, in areas with available transit data, if a user selects point-to-point directions, there is a third new option in addition to the familiar walking and driving directions.

Maps users will be able to view the step-by-step public transportation information, which includes bus, LRT, monorail and Komuter travel options. Users can also see where bus stops and train stations are located.

Traffic and Transit for Maps data comes from a variety of sources, including government departments of transportation, private data providers, and users of Google Maps for mobile, who contribute anonymous speed information through Google's traffic crowdsourcing feature.

Lastly, Google Maps is now available in Bahasa Malaysia, giving Malay native speakers better accessibility and the option of interfacing and navigating with Google Maps using the language they are most comfortable with.

With 60% of Malaysians using Bahasa Malaysia as their primary language and with over 90% proficiency in the language nationwide, the localisation initiative should make it easier for Malaysians to get the most from Maps, says Google. All the enhancements are available on the desktop and mobile versions of Google Maps (Paul, 2012).

5.2.4 User's Driving Behaviour

Different types of user's driving behaviour will also affect the accuracy of the current distance estimation system. For example, the younger generation population such as teens and young adults who just passed their driving license may drive more recklessly at higher speed and acceleration compared to the more matured older generation who are more calm and careful when driving on the road. Some drivers who are impatient may accelerate and use the brake more often compared to other road users and this too will have an impact on the energy consumption from the electric vehicle's battery pack.

Another example would be different weather conditions such as raining and thunderstorm will also affect the driving behaviour of users on the road where they will drive much more slowly and most of the time will result in traffic congestion. When this happens, the electric vehicle will be moving at a much slower speed with less acceleration, and this will result in higher energy consumption where it will affect the accuracy of the conventional distance estimation system.

To solve this problem, a proposed solution that could be done is by implementing self-learning algorithms to recognise the different driving patterns of different drivers who use the same electric vehicle. A program which may be used to execute the self-learning algorithm could be MATLAB programming.

An example of the application mentioned above is a software named, Waze, which is a free GPS application featuring turn-by-turn navigation, developed by the Israeli start-up Waze Mobile for mobile phones. Waze is different from traditional GPS navigation software as it is a community-driven application and learns from users' driving times to provide routing and real-time traffic updates. It is also free to download and use, as it gathers map data and other information from users who use the service. Additionally, people can report accidents, traffic jams, speed traps, police road blocks and can update roads, landmarks, house numbers information, etc. Waze also helps users find the cheapest, closest gas station around them or along their route (Waze, 2012).

5.2.5 Data Extraction in Continuous Form from Google Earth's Elevation Profile

One of the discussions from the results was to improve the data extraction from Google Earth's elevation profile where the distance and elevation information can be extracted into a continuous form instead of in steps and sample size of every 10 meters. The proposed methods that can be implemented to execute such a function are by using differential and integral equations.

5.2.6 Distance Cost Calculation Algorithm

Another interesting feature that can be implemented into the Contour Positioning System is an algorithm that can calculate the distance cost of a journey in terms of the amount of battery energy used and the cost of charging the battery to 100%. This will be useful for users to estimate if it will be more worth it to travel by public transport or drive straight to the desired destination.

For example, the cost of charging an electric vehicle from 0 to 100% is RM20.00. A journey from point A to B requires 50% of battery energy which cost RM10.00. Taking a public transport such as the Putra LRT to the same destination only cost RM2.50. Therefore, this algorithm can be developed into a software module that can be installed into the CPS and help the user to make a wise decision between travelling using their electric vehicle or public transport. This algorithm can even be patented if successfully developed and be implemented into injection combustion engine(ICE) vehicles. The concept of implementation will be almost the same; the only difference is the algorithm will calculate the distance cost of a journey in terms of the amount of petrol/gas used and the cost of refuelling the ICE vehicle to full tank.

5.2.7 Real-time Estimation

Another complementary feature that can be implemented into the Contour Positioning System is a real-time distance estimation system where the velocity, acceleration, traffic condition and changing of driving routes by the driver of the electric vehicle can be feedback into the system by real-time and the new estimated time and distance needed will be simulated on the spot. This feature is also important because the vehicle may not be moving at a constant velocity and acceleration due to different traffic conditions and sometimes, the driver may want to use a different route to reach their destination. Therefore, this feature will provide flexibility to the user when they suddenly decided to change driving routes and drive at different speed but the CPS still can provide real-time distance estimation on the spot.

5.2.8 Lithium Battery Degradation Over Time

Another important feature that should be implemented into the Contour Positioning System is by taking into consideration the battery pack energy degradation over time. This factor is very important because even for a lithium-ion battery, it has a finite amount of life cycles and as it approaches the end of its life time, the battery's performances to retain energy capacity will degrade over time. This is essential for an accurate distance estimation system because the same battery will not produce the same performance now and five years later.

5.2.9 More Simulations for Each Driving Profile

The CPS simulations can also be improved by conducting more case studies for all the different driving profiles. For example, in this research, there are four notable driving profiles which are uphill, downhill, highway and zero gradients travelling. Each driving profiles should have at least 10 different simulations to have a better average and tabulation of results. This means a total of 40 different simulation results. However, when this research was done, each simulation takes approximately two weeks to collect the data and compute the results. Therefore, to conduct 40 different simulations, it will take a long time and proper planning should be done before starting this experiment. New driving profiles can also be added into the simulations such as town and cities driving etc.

5.2.10 Compare CPS against Conventional Distance Estimation Method on a Same Road

Another type of simulation that can be done is by comparing CPS against the conventional distance estimation on the same road and same distance. However, to conduct this, a real electric vehicle is needed to obtain the results for the conventional distance estimation simulation. Therefore, this goes back to the problem of funding and collaboration with industrial automotive manufacturers. When these results can be obtained, it can be compared to any simulations done with the CPS in real-time. This simulation is also important to show the real and actual difference between the conventional distance estimation and CPS. For this research to be conducted, a real prototype of CPS is also needed to be developed.

5.3 Work in Progress

5.3.1 Applying for TechnoFund Government Research Grant

The current work in progress is to apply for the TechnoFund government research grant which ranges from RM1 million to RM3 million. The money from the grant will be used to purchase either the Proton Saga EV which will cost approximately RM80,000 or the Nissan Leaf which will cost

RM120,000 to RM140,000. Both electric vehicles are expected to be officially commercialised in Malaysia by end of year 2013 (Nissan LEAF, 2012). The purchase of a real electric vehicle will help to bring the CPS from a research project into a commercial product that can be sold in the market.

First EV on sale now

IN A HURRY TO GO ELECTRIC? THEN THE I-MIEV IS WHAT YOU NEED.

Oda (left) with Iwata, the first i-MiEV owner in Malaysia, who is symbolically charging his car.

That's a 2-DIN touchscreen entertainment system with GPS navigation.

MITSUBISHI'S i-MiEV electric car has become the first electric car to go on sale with a princely tag of RM136,118.50 on-the-road without insurance.

Easily the greenest car on local roads, the four-seater i-MiEV is no slouch and its electric motor produces 49kW of power and 180Nm of torque for a lively driving experience.

Based on the petrol "i" mini car. the i-MiEV has a top speed of 130kph and its lithium ion battery pack can be fully charged in eight hours using a household plug point to provide a driving range of 150km.

The electric vehicle (EV) comes with a free five-year maintenance and five-year warranty (or 100,000km) package which covers labour cost for periodical vehicle check, air conditioner filter and brake fluid.

Features are six airbags, anti-lock braking system, stability and traction control, electronic brake force distribution, 2-DIN touch screen entertainment system with GPS navigation, solar tint film, auto climate control air conditioner, double LED headlamps, LED rear combination lamps, electric power steering and aero wiper blade.

The driving cost of the i-MiEV is estimated at 3 sen per km compared against 15 sen to 20 sen per km for a small petrol-powered vehicle.

Available colours are Frost White and two-tone Red Frost White.

Speaking at the launch at Mitsubishi Motors Malaysia (MMM)'s first official EV centre at SAG Star dealership on Jalan Chan Sow Lin, Kuala Lumpur last week, MMM chief executive officer Tetsuya Oda said the outlet is equipped with a free charging facility for all EV customers, with i-MiEV customers given first priority.

He said the i-MiEV's introduction was in-line with the Government's call to reduce carbon emission by 40% by the year 2020.

The i-MiEV, Oda said, had been well received since its introduction in Japan in July 2009.

"Sales to private customers in Japan started in April 2010. Since then, Mitsubishi Motors Corp has sold more than 11,434 units of i-MiEV and MINICAB-MiEV in Japan and has exported to 31 countries throughout Europe, US, Canada, Hong Kong, Australia, New Zealand, Chile, Singapore and other markets,' he said.

Oda also said MMM was confident of meeting its i-MiEV sales target of 50 units for the fiscal year ending March 2014 and the plan to expand its EV sales and service network across Peninsular and East Malaysia by opening another four EV centres within the next year.

Oda later presented an exclusive designed i-MiEV shirt to the first i-MiEV owner in Malaysia, Masaharu Iwata.

Iwata, attached to Mitsubishi Corp Kuala Lumpur, said he wanted the i-MiEV because of the electric vehicle's vibration free and quiet running.

"For city driving, the i-MiEV is perfect as its compact dimension makes the car easy to manoeuvre and park," he said, adding that charging stations in Kuala Lumpur city centre made it convenient for him to "fuel up" his vehicle.

"With this electric car, I will only pull into petrol stations to buy cigarettes," he laughs.

Figure 5.1: Mitsubishi i-MiEV in Malaysia

In Figure 5.1 shown above, the Mitsubishi i-MiEV electric vehicle was already on sale in Malaysia during March 2013 with a price tag of RM136,118.50 on-the-road without insurance. It is the very first electric vehicle on sale in Malaysia and it is easily the greenest car on local roads.

5.3.2 Meeting with Ministry of Energy, Green Technology and Water (KeTTHA), Proton Executives, Green Tech Malaysia and UTAR Management team

Another work in progress was the collaborative effort between UTAR management team represented by Professor Dr. Faidz, Director of Institute of Postgraduate Studies and Research from UTAR and Dr. Chew Kuew Wai, Proton executives represented by engineers from their electric vehicle team, and the KeTTHA which is represented by their secretary team. The meeting and discussions was done on the 19th of April 2012, Bilik Bincang IV, Level 3 at KeTTHA main office. The main objective of the meeting was to commercialize the Contour Positioning System into a market ready product which can be implemented into a real electric vehicle.

Figure 5.2: Group photo with KeTTHA, Proton, Green Tech Malaysia and UTAR Executives

5.3.3 Applying for Cradle U-CIP Catalyst

Another fund application in progress is the University-CIP Catalyst (U-CIP Catalyst) pre-seed conditional grant offered by Cradle Fund Sdn Bhd under the CIP for the Contour Positioning System(CPS) prototype development. Similar to the CIP Catalyst, the U-CIP Catalyst also offers conditional grants of up to RM150,000 (via two tranches of RM100,000 and RM50,000) to groups of innovative individuals with technology-based ideas in the ICT, non-ICT and high growth technology industries.

However, the U-CIP Catalyst is targeted at researchers and/or inventors based in local research institutes, private and public universities, colleges and institutes of higher education, as well as the various commercialisation units within each of these organisations. It focuses specifically on ideas that come out of the academic or research arena and addresses the special challenges and needs that researchers, innovators or students face in developing and commercialising their research ideas.

The primary objective of U-CIP Catalyst is to facilitate the transformation of innovative technology-based research output into commercially viable ventures as the first step in the commercialisation roadmap for these organisations. Alike the CIP Catalyst, U-CIP Catalyst recipients are also given a 12-month period to complete the development of their prototypes or proofs-of-concept.

5.4 Achievements

5.4.1 Patent (PI 2012002380)

Contour Positioning System – A Method of Estimating Electric Vehicle Battery Capacity and Distance Travelled Accurately Using Various Types of Elevation Profiles and Data

ADASTRA™
An Intellectual Property Firm

PATENT
MOHAN K
PC YAN
TRADEMARK/LEGAL
FRANCHISE/GRANTS
BRANDING/DESIGN

OUR REF : P/UTAR/12MY7/Yan
YOUR REF : PI 2012002380
DATE : 29 May 2012

Universiti Tunku Abdul Rahman
Level 2, Plaza Hamodal
Lot No. 15, Jalan 13/2
46200 Petaling Jaya,
Selangor Darul Ehsan
Attn : Mr Ronnie Ooi/Dr. Chew Kuew Wai

By Post

Dear Sir,

Re : **New Patent Application in Malaysia – No. PI 2012002380**
Applicant : Universiti Tunku Abdul Rahman
Invention : Contour Positioning System – A Method of Estimating Electric Vehicle Battery Capacity And Distance Travelled Accurately Using Various Types of Elevation Profiles And Data

We refer to the above matter.

We confirm having filed the above-mentioned patent application in accordance with your instructions in Malaysia on 28 May 2012. We enclose a copy of the request form as filed for your records.

The Patent Office will shortly issue a Certificate of Filing confirming the date of filing and reflecting the official application number, which we shall forward to you upon receipt thereof.

We also enclose herewith our invoice No. **Inv/UTAR/5253/12** for the said matter.

Further progress will be reported.

Yours faithfully,

MOHAN K / PC YAN
PATENT AGENT REGN. NO. PA04/0141

Figure 5.3: CPS Patent Filing

5.4.2 Journal Publications

Published:

1. Paper Title: Contour Positioning System - New Travelling Distance Estimation Method for Electric Vehicle (International Journal of Engineering and Technology Innovation (IJETI), ISSN 2223-5329 (Print), ISSN 2226-809X (Online)) – Co-Author

Pending:

2. Paper Title: Contour Positioning System(CPS) – A Novel Range Prediction Technique for Electric Vehicles Using Simulations (IEEE Transactions on Intelligent Transportation Systems, Impact Factor: 3.452) – Main Author

5.4.3 Paper Publications

Published:

1. Paper Title: Contour Positioning System – Method of Data Extraction for Contour Positioning (IEEE 2012 Conference on Sustainable Utilization and Development in Engineering and Technology (STUDENT 2012)) – Co-Author

5.4.4 CPS Presentation to KeTTHA

Attendees: YB Dato' Sri Peter Chin Fah Kui, Tan Sri Dr. Fong Chan Onn, Ir. Prof. Dato' Dr. Chuah Hean Teik

Date: March 2012

Figure 5.4: CPS Presentation to KeTTHA

5.4.5 Collaboration Discussions between APM Engineering & Research Sdn Bhd and UTAR EV Team

Date: March 2012

Figure 5.5: Industrial Visitation to APM Engineering & Research

5.4.6 Collaboration Discussions between Proton, KeTTHA, Green Tech Malaysia and UTAR EV Team

Attendees: Executives from Proton, KeTTHA and Green Tech Malaysia, Prof. Dr Faidz bin Abd Rahman, Dr. Chew Kuew Wai

Date: April 2012

Figure 5.6: Collaboration Discussions at KeTTHA Office

5.4.7 IEEE STUDENT 2012: Best Exhibition Award

Exhibition: Second Runner-up for Project titled 'Contour Positioning System'

Date: October 2012

10th anniversary 2002 - 2012 UTAR

STUDENT 2012

IEEE Student Branch UNIVERSITI TUNKU ABDUL RAHMAN UTAR

2012 IEEE Conference on
SusTainable Utilization Development in ENgineering and Technology
From 6th to 9th October 2012
Present this
Second Runner Up of Best Exhibition Award
to
Gan Yu Han
For the project entitled
Contour Positioning System (CPS)

Anson Tan Kock Li
Conference Director
STUDENT 2012

Dr. Wang Xin
General co-Chair
STUDENT 2012

Figure 5.7: IEEE STUDENT 2012 Best Exhibition Award Certificate

5.4.8 100 Best Technopreneur Competition 2012: Young Technopreneur Category

Award: Best Young Technopreneur Award

Business model: Contour Positioning System (CPS)

Date: October 2012

Figure 5.8: Best Young Technopreneur Award Presentation

Figure 5.9: Best Young Technopreneur Award Certificate

5.4.9 Malam Citra Inovasi 2013 – Kementerian Pengajian Tinggi

Invention: Sistem Penempat Kontur (CPS) – Sistem Ukur Jarak bagi Kenderaan Elektrik

Date: March 2013

Figure 5.10: Malam Citra Inovasi 2013 Certificate

5.4.10 24th International Invention, Innovation & Technology Exhibition (ITEX) 2013

Award: Bronze Medal

Invention: Contour Positioning System – Novel Distance Estimation Method for an Electric Vehicle

Date: May 2013

Figure 5.11: ITEX 2013 CPS Presentation

5.4.11 Innovation Business Opportunities 2013 – Agensi Inovasi Malaysia

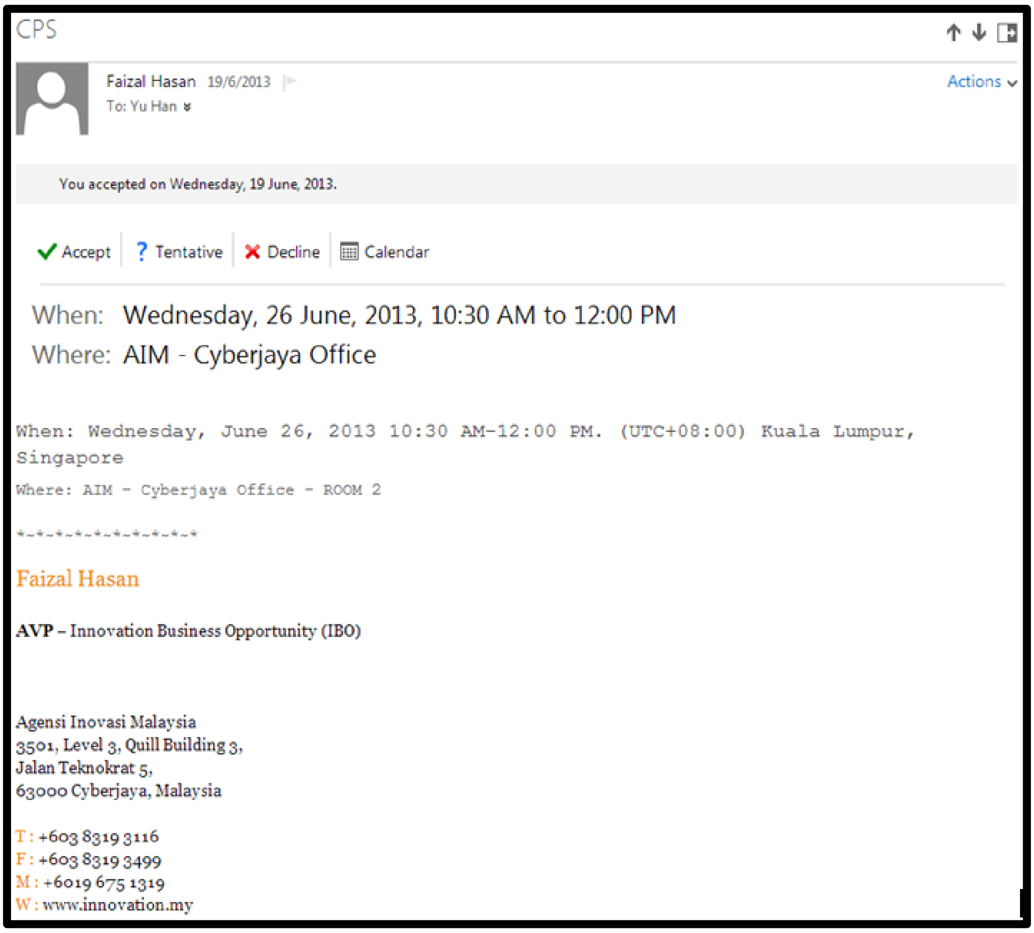
Presentation: Contour Positioning System – A Novel Range Prediction Technique for Electric Vehicles Using Simulations

Date: 26th June 2013 (Ongoing)

Link: http://innovation.my/pdf/initiatives_biz_opportunities/v4/AIM_IBO4.pdf

http://innovation.my/upload/pdf/cci_08_4IND003_CONTOUR_POSITIONING_SYSTEM.pdf

*CPS is listed on page 101 and 102.


CPS

Faizal Hasan 19/6/2013

To: Yu Han

Actions

You accepted on Wednesday, 19 June, 2013.

Accept | ? Tentative | Decline | Calendar

When: Wednesday, 26 June, 2013, 10:30 AM to 12:00 PM

Where: AIM - Cyberjaya Office

When: Wednesday, June 26, 2013 10:30 AM-12:00 PM. (UTC+08:00) Kuala Lumpur, Singapore

Where: AIM - Cyberjaya Office - ROOM 2

~~*~*~*~*~*~*~*~*

Faizal Hasan

AVP – Innovation Business Opportunity (IBO)

Agensi Inovasi Malaysia
3501, Level 3, Quill Building 3,
Jalan Teknokrat 5,
63000 Cyberjaya, Malaysia

T : +603 8319 3116
F : +603 8319 3499
M : +6019 675 1319
W : www.innovation.my

Figure 5.12: Innovation Business Opportunities 2013 Invitation

CHAPTER 6

PATENT REFERENCES

6.1 Method for Battery Capacity Estimation (December 2009)

An embodiment contemplates a method for estimating a capacity of a battery. A state of charge is determined at a first instant of time and at a second instant of time. A difference in the state of charge is determined between the first instant of time and the second instant of time. A net coulomb flow is calculated between the first instant of time and the second instant of time. The battery capacity is determined as a function of the change in the state of charge and the net coulomb flow.

6.2 System and Method for Managing Electric Vehicle Travel (October 2010)

An apparatus is provided in one example embodiment and includes a power management module configured to receive data associated with travel being proposed by an end user of an electric vehicle. The power management module is configured to suggest a starting time for the travel based on time of use(ToU) rates for electricity consumption and a current level of power in the electric vehicle. In more specific embodiments, the data associated with the travel includes a starting location, an ending location, and a proposed drive time. In other embodiments, the power management module is further configured to interface with a mapping tool in suggesting the starting time for the end user. The power management module can be configured to obtain the ToU rates from a utility, and the ToU rates are provided as a function of time.

6.3 System and Method for Distance Estimation (October 2010)

A mileage estimation system comprising a data collection module, a route determination module, a learning module, and a mileage calculation module is provided. The data collection module receives data corresponding to a position and time of a moving asset from a remote location and the route determination module obtains information from a map database for determining a plurality of routes between at least two locations of the moving asset. The learning module in the system determines a route travelled by the moving asset from the plurality of routes based on mileage estimation criterion, and the mileage calculation module estimates the distance travelled by the moving asset based on the route travelled by the moving asset.

6.4 Method for Estimating the Range of a Motor Vehicle (May 2011)

A method is provided for estimating the range of a motor vehicle based on a quantity of energy carried in the motor vehicle. The method enables a driver to limit a maximum permissible velocity and/or a maximum permissible acceleration and/or a maximum performance level for a comfort system. The method also detects the route profiles surrounding the motor vehicle, in particular an altitude profile and/or a road category. A computer device calculates and displays a still possible range at least on the basis of the limitation which has been carried out, the detection route profiles and the still available quantity of energy.

6.5 Car Navigation System (March 2011)

A car navigation system solves the problem that the emission test cycle fuel consumption rate indicates the energy consumption per unit distance covered following a prescribed emission test cycle procedure, and therefore, cannot produce a highly accurate prediction value reflecting the landform and traffics along a route. So, the test cycle characteristic values independent of the vehicle model for vehicle energy consumption in a specified running condition are calculated, and the vehicle energy consumption parameter of the engine or the motor is estimated from the basic vehicle specifications such as the vehicle weight, the power supply type, the emission test cycle fuel consumption rate, the test cycle characteristic values in the emission test cycle and the vehicle characteristics. Using the basic vehicle specifications and the energy consumption parameter, the energy consumption is predicted taking the landform and traffics into consideration.

6.6 Closely Related Patents to CPS

6.6.1 US5815824 - Navigation System for Electric Automobile

App. Date: 29-September-1998 ; Applicant: Mitsubishi Motors Corp

A navigation system suitable for use in an electric automobile, especially hybrid electric automobiles, easily and properly controls charging state of a battery in the electric automobile while making use of characteristic features of the navigation system. The navigation system is mounted on the electric automobile. A destination, to which one wants to drive by the automobile, is inputted as drive plan information. Based on a distance planned to be driven by the automobile to the destination and a remaining capacity of the battery determined by remaining capacity detector, it is determined whether the automobile can reach the destination with the remaining capacity of the battery.

The present invention relates to a navigation system for an electric automobile which enable to determine the battery capacity of vehicle whether battery is sufficient to reach a desired destination meanwhile to provide road map information. In contrast to present claimed invention, prior art however does not provide vehicle battery estimation based on road elevation from road map other than giving suggested route to destination and charging point. Present claimed invention moreover relates to contour positioning system (CPS) which has better estimation on the vehicle battery usage based on the road elevation, regenerative energy and accuracy on battery usage.

6.6.2 US2011257879 - Route Guidance Apparatus, Route Guidance Method and Computer System

App. Date: 20-october-2011 ; Applicant: Sony Corp

There is provided a route guidance apparatus including a route search unit which searches for at least one route, to a predetermined destination, which is to be travelled by an electric vehicle propelled by electric power stored in a secondary battery provided within the vehicle, and a power consumption calculation unit which calculates power consumption of the electric vehicle when a route to a destination, which was searched for by the route search unit, is travelled by the electric vehicle, based on information on electric power to be consumed when the electric vehicle travels and geographical information relating to the route.

The present invention relates to a navigation system which in search for a route to destination, suggested a less power consumption route and calculate power consumption. In present invention, power consumption due to operation of power consuming device and action of acceleration and brake are all taking into consideration in power consumption calculation. In comparison, present claimed invention which relates to vehicle battery usage estimation is able to provide a better accuracy and precise calculation of power consumption. A series of battery SOC calculation is performed and road slope angle is included in system.

6.6.3 US2011060495 - Method of Predicting Energy Consumption, Apparatus for Predicting Energy Consumption, and Terminal Apparatus

App. Date: 10- March-2011 ; Applicant: Clarion Co Ltd

An object of the invention is to predict energy consumptions of a vehicle, using geographic characteristic values which are independent from particular driving patterns and vehicle parameters and unique to respective links. A navigation server predicts energies which are consumed when a vehicle runs on links. The navigation server calculates geographic characteristic values of respective links, the geography of the each link affecting the consumption energy with the geographic characteristic values, the calculation being based on energy consumptions collected from probe vehicles, and calculates predicted energy consumption of each link selected as a processing target, based on the geographic characteristic values. A navigation terminal obtains these predicted energy consumptions and performs route search with the obtained predicted energy consumptions as costs.

The present invention relates to vehicle power consumption based on geographical characteristic value and driving patterns of a user. In addition, the route guide section is likely to provide a route that can minimize the energy consumption using a minimum-cost route search algorithm such as Dijkstra’s algorithm together with information on connection between links in the road. Present claimed invention whereas be able to provide better estimation on the vehicle battery usage using formula by taking account the road slope angles and elevation of the path from origin to destination.

6.6.4 JP2006115623 - Travelable Distance Estimation System

App. Date: 27-April-2006 ; Applicant: Fuji heavy Ind ltd

Problem to be solved: to provide a travelable distance estimation system that can finely estimate a travelable distance on the basis of the remaining capacity of an in-vehicle battery of an electric automobile. ; Solution: the travelable distance estimation system 1 is constituted of a plurality of the electric automobiles 2 and a data centre 3. The electric automobile 2 comprises: a battery management device 22 that can measure the remaining capacity or the like of the in-vehicle battery; a storing medium 28 stored with map information; a communication device 24; and a display input device 21 that can set a destination or a route, and displays the estimated travelable distance. The data centre 3 comprises a data base 35 wherein a link number, a battery consumption amount and the like are stored so as to be made to associate with one another, and the map information is stored; a navigation server 32 that can select the route; and an analysis server 33 that reads out the battery consumption amount at each link belonging to the route. The data centre estimates the travelable distance of the electric automobile 2 by comparing the remaining capacity of the in-vehicle battery and the battery consumption amount at each link belonging to the route.

The present invention relates to travelable distance estimation system which equipped with a map storage medium, a communication device and a display input unit. Based on the map information stored, one is able to know the distance a vehicle can travel with the remaining capacity of battery. The prior art however does not disclose any information related to power consumption calculation particularly based on the road elevation data. Considering that present claimed invention taking account every change of the elevation in database for calculation.

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CPS_main

```
close all;
clear all;
clc;
fname='CPS.xls';
[txt,data,all]=xlsread(fname,1); %extract data, text and all
from 'CPS.xls' excel file, sheet 1, xlsread is a MATLAB
function
%disp(txt(7:10,1));
x=1;
i=0;
while (x)
    i=i+1;
    if strcmp(data(i,2),'')
        x=0;
        i=i-1;
        temp=i;
    end
end

temp2= length(data(:,2))-temp;
temp3= length(data(:,1))-temp2;

data=str2double(data(7:temp3,1:2));
disp(data);

minimum_power=4.646489;
CPS_FUNCTION(data,minimum_power,fname) %Yu Han's Saga EV CPS
main function (change specifications data and variables in
here)
%title('Elevation VS Distance Graph');
%xlabel('Distance');
%ylabel('Elevation');
grid on;

%clear all;
%[data,txt,all]=xlsread('CPS.xlsx',2); %extract data, text and
all from 'CPS.xls' excel file, sheet 2, xlsread is a MATLAB
function
%E=data;
%CPS_MAIN_FUNCTION(E) %Yu Han's Saga EV CPS main function
(change specifications data and variables in here)
```

CPS_FUNCTION

```
function CPS_FUNCTION(data,minimum_power,fname)
SagaEV_Battery_Energy_kWh=15.9;
Distance=data(:,1);
%disp(Distance);

Elevation=data(:,2);
%disp(Elevation(:,1));



for i=2:length(Distance(:,1))
    count=i-1;
    Distance_Difference(count,1) = Distance(i,1)-
Distance(count,1);
end
%disp(Distance_Difference);

for i=2:length(Elevation(:,1))
    count=i-1;
    Elevation_Difference(count,1) = Elevation(i,1)-
Elevation(count,1);
end
%disp(Elevation_Difference);


for i=1:length(Elevation_Difference(:,1))
Calculated_Slope_Degree(i,1) =
(abs(Elevation_Difference(i,1))/Elevation_Difference(i,1))*asin
d(abs(Elevation_Difference(i,1))/Distance_Difference(i,1));
end
%disp(Calculated_Slope_Degree);

for i=1:length(Calculated_Slope_Degree(:,1))
Calculated_Slope_Percentage(i,1) =
tan(Calculated_Slope_Degree(i,1) * pi/180) * 100;
end
%disp(Calculated_Slope_Percentage);

if 0
Measured_Slope_Percentage=data(:,3);
for i=1:length(Measured_Slope_Percentage(:,1))
    if Measured_Slope_Percentage(i,1)>0
    Motive_Power_kW (i,1)= 2.964695 *
Measured_Slope_Percentage(i,1) + minimum_power;
    else
       Motive_Power_kW (i,1)=minimum_power;
    end
end
end

if 1
for i=1:length(Calculated_Slope_Percentage(:,1))
    if Calculated_Slope_Percentage(i,1)>0
```

```
    Motive_Power_kW (i,1)= 2.964695 *
Calculated_Slope_Percentage(i,1) + minimum_power;
    else
       Motive_Power_kW (i,1)=minimum_power;
    end
end
end

%disp(Motive_Power_kW);

for i=1:length(Distance_Difference(:,1))
Time_Taken_Hour(i,1) = Distance_Difference(i,1)/90000;
end
%disp(Time_Taken_Hour);


for i=1:length(Time_Taken_Hour(:,1))
Energy_Used_kWh(i,1) = Motive_Power_kW(i,1) *
Time_Taken_Hour(i,1);
end
%disp(Energy_Used_kWh);

Total_Energy_Usage=sum(Energy_Used_kWh(:,1));
Total_Energy_Percentage=Total_Energy_Usage/SagaEV_Battery_Energ
y_kWh.*100;
%disp(Percentage_total_energy);

%%
data_compile=data(:,1:2);
%for i=1:length(Distance_Difference(:,1))
%data_compile(i+1,3)=data(i,3);
%end
for i=2:length(Distance_Difference(:,1))+1
data_compile(i,4)=Distance_Difference(i-1,1);
data_compile(i,5)=Elevation_Difference(i-1,1);
data_compile(i,6)=Calculated_Slope_Degree(i-1,1);
data_compile(i,7)=Calculated_Slope_Percentage(i-1,1);
data_compile(i,8)=Motive_Power_kW(i-1,1);
data_compile(i,9)=Time_Taken_Hour(i-1,1);
data_compile(i,10)=Energy_Used_kWh(i-1,1);
end
data_compile(length(Distance_Difference(:,1))+2,10)=Total_Energ
y_Usage;
data_compile(length(Distance_Difference(:,1))+3,10)=Total_Energ
y_Percentage;
%disp(data_compile);
xlswrite(fname,data_compile,2);

str=sprintf('Total Energy Needed (kWh) = %.6f
kWh',Total_Energy_Usage);
disp(str);
str=sprintf('Total Energy Needed (%%)    =
%.2f%%',Total_Energy_Percentage);
disp(str);

%plot(data(:,1),data(:,2));
x1 = data(:,1);
y1 = data(:,2);
x2 = data(2:length(data(:,1)),1);
```

```
y2 = Energy_Used_kWh(:,1);
hl1 = line(x1,y1,'Color','r');
%title('Title');
xlabel('Distance (m)');
ylabel('Elevation (m)');
ax1 = gca;
set(ax1,'XColor','r','YColor','r')
ax2 = axes('Position',get(ax1,'Position'),...
            'XAxisLocation','top',...
           'YAxisLocation','right',...
           'Color','none',...
           'XColor','k','YColor','k');

 hl2 = line(x2,y2,'Color','k','Parent',ax2);
 ylabel('Energy used (kWh)');
%plot(data(2:length(data(:,1)),1),Energy_Used_kWh(:,1));
%for i=1:10
%    temp(i,1)=i;
%end
%xlswrite('CPS.xlsx',temp,3);
```

Main Case Study Complete Simulation Raw Data and Results

	A	B	C	D	E	F	G	H	I	J
1	10	1496.448	0	0	0	0	0	0	0	0
2	20	1496.957	0	10	0.508911	2.917106	5.095714	19.75373	0.000111	0.002194859
3	30	1497.47	0	10	0.51355	2.943719	5.142283	19.89179	0.000111	0.002210199
4	40	1497.988	0	10	0.517944	2.968931	5.186405	20.0226	0.000111	0.002224733
5	50	1498.511	0	10	0.522461	2.994844	5.231755	20.15705	0.000111	0.002239672
6	60	1499.038	0	10	0.5271	3.021459	5.278334	20.29514	0.000111	0.002255015
7	70	1499.569	0	10	0.531616	3.047373	5.32369	20.42961	0.000111	0.002269956
8	80	1500.105	0	10	0.536133	3.073288	5.36905	20.56408	0.000111	0.002284898
9	90	1500.549	0	10	0.443237	2.540395	4.436733	17.80005	0.000111	0.001977783
10	100	1500.978	0	10	0.428833	2.457786	4.292279	17.37179	0.000111	0.001930198
11	110	1501.406	0	10	0.428833	2.457786	4.292279	17.37179	0.000111	0.001930198
12	120	1501.835	0	10	0.428711	2.457086	4.291055	17.36816	0.000111	0.001929795
13	130	1502.245	0	10	0.40979	2.348582	4.101345	16.80573	0.000111	0.001867303
14	140	1502.636	0	10	0.391113	2.241486	3.914128	16.25068	0.000111	0.001805632
15	150	1503.027	0	10	0.390991	2.240786	3.912904	16.24706	0.000111	0.001805228
16	160	1503.418	0	10	0.391113	2.241486	3.914128	16.25068	0.000111	0.001805632
17	170	1503.809	0	10	0.391113	2.241486	3.914128	16.25068	0.000111	0.001805632
18	180	1504.2	0	10	0.390991	2.240786	3.912904	16.24706	0.000111	0.001805228
19	190	1504.591	0	10	0.391113	2.241486	3.914128	16.25068	0.000111	0.001805632
20	200	1504.982	0	10	0.390991	2.240786	3.912904	16.24706	0.000111	0.001805228
21	210	1505.373	0	10	0.391113	2.241486	3.914128	16.25068	0.000111	0.001805632
22	220	1505.765	0	10	0.391113	2.241486	3.914128	16.25068	0.000111	0.001805632
23	230	1506.156	0	10	0.390991	2.240786	3.912904	16.24706	0.000111	0.001805228
24	240	1506.547	0	10	0.391113	2.241486	3.914128	16.25068	0.000111	0.001805632
25	250	1506.932	0	10	0.385132	2.207189	3.854178	16.07295	0.000111	0.001785883
26	260	1507.292	0	10	0.359985	2.06301	3.602188	15.32588	0.000111	0.001702875
27	270	1507.647	0	10	0.355469	2.037115	3.556935	15.19172	0.000111	0.001687969
28	280	1507.998	0	10	0.350952	2.011221	3.511685	15.05756	0.000111	0.001673063
29	290	1508.345	0	10	0.346436	1.985327	3.466436	14.92342	0.000111	0.001658157
30	300	1508.686	0	10	0.341797	1.958733	3.419967	14.78565	0.000111	0.00164285
31	310	1509.024	0	10	0.337402	1.93354	3.375946	14.65514	0.000111	0.001628349
32	320	1509.357	0	10	0.332764	1.906947	3.329481	14.51738	0.000111	0.001613043
33	330	1509.685	0	10	0.328247	1.881055	3.28424	14.38326	0.000111	0.00159814
34	340	1510.009	0	10	0.323853	1.855863	3.240225	14.25277	0.000111	0.001583641
35	350	1510.328	0	10	0.319214	1.829272	3.193766	14.11503	0.000111	0.001568337

	A	B	C	D	E	F	G	H	I	J
36	360	1510.643	0	10	0.314697	1.80338	3.148532	13.98093	0.000111	0.001553436
37	370	1510.953	0	10	0.310181	1.777489	3.1033	13.84683	0.000111	0.001538536
38	380	1511.258	0	10	0.305542	1.750899	3.056847	13.70911	0.000111	0.001523234
39	390	1511.559	0	10	0.301147	1.725709	3.012841	13.57864	0.000111	0.001508738
40	400	1511.856	0	10	0.296509	1.699119	2.966392	13.44094	0.000111	0.001493437
41	410	1512.148	0	10	0.292114	1.67393	2.92239	13.31048	0.000111	0.001478943
42	420	1512.795	0	10	0.647339	3.711574	6.486995	23.87845	0.000111	0.002653161
43	430	1513.728	0	10	0.932983	5.353387	9.370707	32.42778	0.000111	0.003603086
44	440	1514.652	0	10	0.923828	5.300703	9.277958	32.1528	0.000111	0.003572534
45	450	1515.567	0	10	0.914917	5.249429	9.187705	31.88523	0.000111	0.003542803
46	460	1516.473	0	10	0.905762	5.196755	9.095002	31.6104	0.000111	0.003512266
47	470	1517.37	0	10	0.896729	5.144787	9.003558	31.33929	0.000111	0.003482144
48	480	1518.257	0	10	0.887695	5.092823	8.912136	31.06826	0.000111	0.003452028
49	490	1519.136	0	10	0.87854	5.040161	8.819502	30.79362	0.000111	0.003421514
50	500	1520.005	0	10	0.869629	4.988908	8.72936	30.52638	0.000111	0.00339182
51	510	1520.866	0	10	0.860474	4.936255	8.63677	30.25188	0.000111	0.00336132
52	520	1521.717	0	10	0.85144	4.884308	8.545436	29.9811	0.000111	0.003331233
53	530	1522.56	0	10	0.842285	4.831663	8.452889	29.70673	0.000111	0.003300747
54	540	1523.393	0	10	0.833374	4.780426	8.362831	29.43973	0.000111	0.003271081
55	550	1524.217	0	10	0.824219	4.727789	8.270327	29.16549	0.000111	0.00324061
56	560	1525.032	0	10	0.815186	4.675858	8.179077	28.89496	0.000111	0.003210551
57	570	1525.839	0	10	0.806152	4.62393	8.087847	28.62449	0.000111	0.003180499
58	580	1526.636	0	10	0.796997	4.571305	7.995405	28.35043	0.000111	0.003150047
59	590	1528.242	0	10	1.606445	9.244309	16.27584	52.89939	0.000111	0.00587771
60	600	1529.969	0	10	1.72644	9.941585	17.52759	56.61046	0.000111	0.006290051
61	610	1531.718	0	10	1.749023	10.07298	17.76405	57.31149	0.000111	0.006367943
62	620	1533.489	0	10	1.771729	10.20513	18.00208	58.01717	0.000111	0.006446353
63	630	1535.284	0	10	1.794434	10.33734	18.24041	58.72374	0.000111	0.00652486
64	640	1537.101	0	10	1.817017	10.46889	18.47775	59.42739	0.000111	0.006603043
65	650	1538.94	0	10	1.839722	10.60121	18.71668	60.13575	0.000111	0.00668175
66	660	1540.591	0	10	1.650635	9.500922	16.73592	54.26337	0.000111	0.006029264
67	670	1542.006	0	10	1.414795	8.133467	14.29171	47.01704	0.000111	0.005224116
68	680	1543.375	0	10	1.369385	7.870728	13.82408	45.63066	0.000111	0.005070073
69	690	1544.699	0	10	1.324097	7.60886	13.35859	44.25063	0.000111	0.004916736
70	700	1545.978	0	10	1.278931	7.347858	12.8952	42.87683	0.000111	0.004764092

	A	B	C	D	E	F	G	H	I	J
71	710	1547.212	0	10	1.233521	7.085599	12.43013	41.49805	0.000111	0.004610894
72	720	1548.4	0	10	1.188232	6.824193	11.96711	40.12531	0.000111	0.004458368
73	730	1549.543	0	10	1.142944	6.562931	11.50484	38.75482	0.000111	0.004306091
74	740	1550.641	0	10	1.097534	6.301101	11.04205	37.3828	0.000111	0.004153644
75	750	1551.605	0	10	0.9646	5.535355	9.691187	33.3779	0.000111	0.003708656
76	760	1552.281	0	10	0.675903	3.875596	6.774525	24.73089	0.000111	0.002747877
77	770	1552.984	0	10	0.703125	4.031936	7.048695	25.54372	0.000111	0.002838191
78	780	1553.714	0	10	0.730225	4.187606	7.321793	26.35337	0.000111	0.002928152
79	790	1554.472	0	10	0.757324	4.343307	7.595054	27.16351	0.000111	0.003018167
80	800	1555.256	0	10	0.784668	4.500443	7.870948	27.98145	0.000111	0.00310905
81	810	1556.068	0	10	0.811768	4.656209	8.144555	28.79261	0.000111	0.003199179
82	820	1556.907	0	10	0.838989	4.812712	8.419578	29.60797	0.000111	0.003289774
83	830	1557.773	0	10	0.866211	4.969251	8.69479	30.42389	0.000111	0.003380432
84	840	1558.667	0	10	0.893311	5.125124	8.968964	31.23673	0.000111	0.003470748
85	850	1559.587	0	10	0.920532	5.281738	9.244574	32.05383	0.000111	0.003561537
86	860	1560.535	0	10	0.947632	5.43769	9.519156	32.86788	0.000111	0.003651987
87	870	1561.51	0	10	0.974976	5.595087	9.796428	33.68991	0.000111	0.003743323
88	880	1562.512	0	10	1.002075	5.751121	10.07145	34.50525	0.000111	0.003833917
89	890	1563.541	0	10	1.029175	5.907197	10.34669	35.32127	0.000111	0.003924585
90	900	1564.598	0	10	1.056519	6.064724	10.62465	36.14534	0.000111	0.004016148
91	910	1565.681	0	10	1.083618	6.22089	10.90037	36.96276	0.000111	0.004106973
92	920	1566.17	0	10	0.48877	2.801559	4.893544	19.15435	0.000111	0.002128262
93	930	1566.039	0	10	-0.13123	-0.75189	-1.31237	4.646489	0.000111	0.000516277
94	940	1565.935	0	10	-0.10413	-0.59661	-1.04132	4.646489	0.000111	0.000516277
95	950	1565.858	0	10	-0.07678	-0.43993	-0.76784	4.646489	0.000111	0.000516277
96	960	1565.808	0	10	-0.04968	-0.28466	-0.49683	4.646489	0.000111	0.000516277
97	970	1565.786	0	10	-0.02246	-0.12869	-0.22461	4.646489	0.000111	0.000516277
98	980	1565.79	0	10	0.004761	0.027277	0.047607	4.78763	0.000111	0.000531959
99	990	1565.822	0	10	0.03186	0.182547	0.318605	5.591056	0.000111	0.000621228
100	1000	1565.881	0	10	0.059082	0.338517	0.590831	6.398122	0.000111	0.000710902
101	1010	1565.968	0	10	0.086182	0.493791	0.861848	7.201607	0.000111	0.000800179
102	1020	1566.081	0	10	0.113525	0.650467	1.135327	8.012387	0.000111	0.000890265
103	1030	1566.222	0	10	0.140625	0.805748	1.406389	8.816004	0.000111	0.000979556
104	1040	1566.389	0	10	0.167725	0.961036	1.677482	9.619712	0.000111	0.001068857
105	1050	1566.584	0	10	0.195068	1.11773	1.951055	10.43077	0.000111	0.001158975

	A	B	C	D	E	F	G	H	I	J
106	1060	1566.807	0	10	0.222168	1.273033	2.222228	11.23472	0.000111	0.001248302
107	1070	1567.056	0	10	0.249268	1.428346	2.493451	12.03881	0.000111	0.001337645
108	1080	1567.333	0	10	0.276611	1.585068	2.767172	12.85031	0.000111	0.001427812
109	1090	1566.803	0	10	-0.52942	-3.03477	-5.30162	4.646489	0.000111	0.000516277
110	1100	1566.251	0	10	-0.55249	-3.16715	-5.53335	4.646489	0.000111	0.000516277
111	1110	1565.753	0	10	-0.49805	-2.85478	-4.98666	4.646489	0.000111	0.000516277
112	1120	1565.309	0	10	-0.44373	-2.5432	-4.44163	4.646489	0.000111	0.000516277
113	1130	1564.919	0	10	-0.3894	-2.23169	-3.897	4.646489	0.000111	0.000516277
114	1140	1564.584	0	10	-0.33496	-1.91954	-3.35149	4.646489	0.000111	0.000516277
115	1150	1564.304	0	10	-0.28064	-1.60816	-2.8075	4.646489	0.000111	0.000516277
116	1160	1564.078	0	10	-0.2262	-1.29612	-2.26254	4.646489	0.000111	0.000516277
117	1170	1563.906	0	10	-0.17188	-0.98482	-1.719	4.646489	0.000111	0.000516277
118	1180	1563.788	0	10	-0.11755	-0.67355	-1.17562	4.646489	0.000111	0.000516277
119	1190	1563.91	0	10	0.12207	0.699429	1.220794	8.265771	0.000111	0.000918419
120	1200	1564.26	0	10	0.349976	2.005622	3.501901	15.02856	0.000111	0.00166984
121	1210	1564.656	0	10	0.395386	2.265984	3.956952	16.37764	0.000111	0.001819738
122	1220	1565.096	0	10	0.440674	2.525693	4.411023	17.72383	0.000111	0.001969314
123	1230	1565.582	0	10	0.485962	2.785454	4.865367	19.07082	0.000111	0.00211898
124	1240	1566.114	0	10	0.53125	3.045272	5.320013	20.4187	0.000111	0.002268745
125	1250	1566.52	0	10	0.406738	2.331082	4.070751	16.71503	0.000111	0.001857225
126	1260	1566.471	0	10	-0.04883	-0.27977	-0.48829	4.646489	0.000111	0.000516277
127	1270	1566.45	0	10	-0.02161	-0.1238	-0.21607	4.646489	0.000111	0.000516277
128	1280	1566.455	0	10	0.005615	0.032173	0.056152	4.812964	0.000111	0.000534774
129	1290	1566.488	0	10	0.032837	0.188142	0.328371	5.620008	0.000111	0.000624445
130	1300	1566.548	0	10	0.059937	0.343413	0.599376	6.423456	0.000111	0.000713717
131	1310	1566.635	0	10	0.087158	0.499386	0.871615	7.230562	0.000111	0.000803396
132	1320	1566.75	0	10	0.114258	0.654663	1.142653	8.034106	0.000111	0.000892678
133	1330	1566.891	0	10	0.141602	0.811344	1.416158	8.844964	0.000111	0.000982774
134	1340	1567.06	0	10	0.168701	0.966632	1.687252	9.648676	0.000111	0.001072075
135	1350	1567.256	0	10	0.195801	1.121928	1.958383	10.4525	0.000111	0.001161389
136	1360	1567.479	0	10	0.223145	1.27863	2.232001	11.26369	0.000111	0.001251521
137	1370	1567.729	0	10	0.250244	1.433943	2.503225	12.06779	0.000111	0.001340865
138	1380	1568.006	0	10	0.277344	1.589266	2.774505	12.87205	0.000111	0.001430228
139	1390	1568.311	0	10	0.304688	1.746001	3.04829	13.68374	0.000111	0.001520416
140	1400	1568.643	0	10	0.331787	1.901349	3.319699	14.48838	0.000111	0.00160982

	A	B	C	D	E	F	G	H	I	J
141	1410	1569.002	0	10	0.358887	2.056711	3.591181	15.29324	0.000111	0.001699249
142	1420	1569.045	0	10	0.043457	0.248991	0.434575	5.93487	0.000111	0.00065943
143	1430	1568.839	0	10	-0.20593	-1.17999	-2.05976	4.646489	0.000111	0.000516277
144	1440	1568.602	0	10	-0.23767	-1.36188	-2.37738	4.646489	0.000111	0.000516277
145	1450	1568.332	0	10	-0.26953	-1.54449	-2.69629	4.646489	0.000111	0.000516277
146	1460	1568.008	0	10	-0.32434	-1.85866	-3.24512	4.646489	0.000111	0.000516277
147	1470	1567.674	0	10	-0.3335	-1.91115	-3.33682	4.646489	0.000111	0.000516277
148	1480	1567.332	0	10	-0.34253	-1.96293	-3.4273	4.646489	0.000111	0.000516277
149	1490	1566.98	0	10	-0.35144	-2.01402	-3.51658	4.646489	0.000111	0.000516277
150	1500	1566.62	0	10	-0.36072	-2.06721	-3.60953	4.646489	0.000111	0.000516277
151	1510	1566.25	0	10	-0.36963	-2.1183	-3.69882	4.646489	0.000111	0.000516277
152	1520	1565.871	0	10	-0.37878	-2.17079	-3.79056	4.646489	0.000111	0.000516277
153	1530	1565.483	0	10	-0.38782	-2.22259	-3.88109	4.646489	0.000111	0.000516277
154	1540	1565.087	0	10	-0.39685	-2.27438	-3.97163	4.646489	0.000111	0.000516277
155	1550	1564.681	0	10	-0.40588	-2.32618	-4.06219	4.646489	0.000111	0.000516277
156	1560	1564.266	0	10	-0.41504	-2.37868	-4.15397	4.646489	0.000111	0.000516277
157	1570	1563.842	0	10	-0.42395	-2.42978	-4.24332	4.646489	0.000111	0.000516277
158	1580	1563.409	0	10	-0.43311	-2.48229	-4.33512	4.646489	0.000111	0.000516277
159	1590	1563.342	0	10	-0.06641	-0.38048	-0.66408	4.646489	0.000111	0.000516277
160	1600	1563.238	0	10	-0.10437	-0.59801	-1.04376	4.646489	0.000111	0.000516277
161	1610	1563.07	0	10	-0.16772	-0.96104	-1.67748	4.646489	0.000111	0.000516277
162	1620	1562.839	0	10	-0.2312	-1.3248	-2.31263	4.646489	0.000111	0.000516277
163	1630	1562.544	0	10	-0.29468	-1.68862	-2.94806	4.646489	0.000111	0.000516277
164	1640	1562.186	0	10	-0.35803	-2.05181	-3.58262	4.646489	0.000111	0.000516277
165	1650	1561.765	0	10	-0.42151	-2.41578	-4.21884	4.646489	0.000111	0.000516277
166	1660	1561.28	0	10	-0.48499	-2.77985	-4.85557	4.646489	0.000111	0.000516277
167	1670	1560.731	0	10	-0.54834	-3.14333	-5.49166	4.646489	0.000111	0.000516277
168	1680	1560.12	0	10	-0.61182	-3.50764	-6.12965	4.646489	0.000111	0.000516277
169	1690	1559.444	0	10	-0.67517	-3.87139	-6.76715	4.646489	0.000111	0.000516277
170	1700	1558.706	0	10	-0.73865	-4.236	-7.40671	4.646489	0.000111	0.000516277
171	1710	1557.904	0	10	-0.80212	-4.60077	-8.04717	4.646489	0.000111	0.000516277
172	1720	1556.91	0	10	-0.99329	-5.70051	-9.98223	4.646489	0.000111	0.000516277
173	1730	1555.723	0	10	-1.1875	-6.81997	-11.9596	4.646489	0.000111	0.000516277
174	1740	1554.463	0	10	-1.26013	-7.23927	-12.7026	4.646489	0.000111	0.000516277
175	1750	1553.596	0	10	-0.86658	-4.97136	-8.69849	4.646489	0.000111	0.000516277

	A	B	C	D	E	F	G	H	I	J
176	1760	1553.855	0	10	0.259033	1.484317	2.591201	12.32861	0.000111	0.001369846
177	1770	1554.06	0	10	0.204834	1.173694	2.04877	10.72047	0.000111	0.001191163
178	1780	1554.21	0	10	0.150391	0.861707	1.504076	9.105617	0.000111	0.001011735
179	1790	1554.306	0	10	0.095947	0.549746	0.959517	7.491164	0.000111	0.000832352
180	1800	1554.348	0	10	0.041748	0.239199	0.417484	5.884202	0.000111	0.0006538
181	1810	1554.335	0	10	-0.01282	-0.07344	-0.12817	4.646489	0.000111	0.000516277
182	1820	1554.268	0	10	-0.06702	-0.38398	-0.67018	4.646489	0.000111	0.000516277
183	1830	1554.147	0	10	-0.12146	-0.69593	-1.21469	4.646489	0.000111	0.000516277
184	1840	1553.971	0	10	-0.17578	-1.0072	-1.75808	4.646489	0.000111	0.000516277
185	1850	1553.741	0	10	-0.23022	-1.31921	-2.30286	4.646489	0.000111	0.000516277
186	1860	1553.456	0	10	-0.28455	-1.63055	-2.84661	4.646489	0.000111	0.000516277
187	1870	1553.117	0	10	-0.33887	-1.94194	-3.39062	4.646489	0.000111	0.000516277
188	1880	1552.724	0	10	-0.39331	-2.25408	-3.93615	4.646489	0.000111	0.000516277
189	1890	1552.276	0	10	-0.44763	-2.5656	-4.48081	4.646489	0.000111	0.000516277
190	1900	1551.774	0	10	-0.50208	-2.87789	-5.02709	4.646489	0.000111	0.000516277
191	1910	1551.218	0	10	-0.55627	-3.18886	-5.57137	4.646489	0.000111	0.000516277
192	1920	1550.897	0	10	-0.32117	-1.84047	-3.21333	4.646489	0.000111	0.000516277
193	1930	1550.733	0	10	-0.16382	-0.93865	-1.6384	4.646489	0.000111	0.000516277
194	1940	1550.56	0	10	-0.17285	-0.99042	-1.72877	4.646489	0.000111	0.000516277
195	1950	1550.378	0	10	-0.18188	-1.04218	-1.81915	4.646489	0.000111	0.000516277
196	1960	1550.187	0	10	-0.19092	-1.09395	-1.90953	4.646489	0.000111	0.000516277
197	1970	1549.987	0	10	-0.20007	-1.14641	-2.00113	4.646489	0.000111	0.000516277
198	1980	1549.784	0	10	-0.20337	-1.1653	-2.03411	4.646489	0.000111	0.000516277
199	1990	1550.294	0	10	0.509766	2.922008	5.104293	19.77916	0.000111	0.002197684
200	2000	1550.817	0	10	0.523315	2.999747	5.240335	20.18248	0.000111	0.002242498
201	2010	1551.354	0	10	0.537109	3.078892	5.378858	20.59316	0.000111	0.002288129
202	2020	1551.905	0	10	0.550537	3.155941	5.513733	20.99303	0.000111	0.002332558
203	2030	1552.469	0	10	0.564209	3.234397	5.651092	21.40025	0.000111	0.002377806
204	2040	1553.047	0	10	0.577759	3.312158	5.787255	21.80394	0.000111	0.002422659
205	2050	1553.638	0	10	0.591309	3.389926	5.923451	22.20771	0.000111	0.002467524
206	2060	1554.243	0	10	0.60498	3.468401	6.060906	22.61523	0.000111	0.002512803
207	2070	1554.861	0	10	0.61853	3.546181	6.197169	23.0192	0.000111	0.002557689
208	2080	1555.494	0	10	0.63208	3.623968	6.333465	23.42328	0.000111	0.002602587
209	2090	1556.269	0	10	0.775879	4.449931	7.782249	27.71848	0.000111	0.003079831
210	2100	1557.077	0	10	0.807495	4.631649	8.101407	28.66469	0.000111	0.003184966

	A	B	C	D	E	F	G	H	I	J
211	2110	1557.912	0	10	0.834717	4.788146	8.3764	29.47996	0.000111	0.003275551
212	2120	1558.773	0	10	0.861816	4.943977	8.650348	30.29213	0.000111	0.003365793
213	2130	1559.662	0	10	0.889038	5.100547	8.925725	31.10854	0.000111	0.003456505
214	2140	1560.579	0	10	0.91626	5.257155	9.201303	31.92555	0.000111	0.003547283
215	2150	1561.522	0	10	0.943481	5.413803	9.477089	32.74317	0.000111	0.00363813
216	2160	1562.493	0	10	0.970581	5.569788	9.751852	33.55776	0.000111	0.003728639
217	2170	1563.491	0	10	0.997803	5.726518	10.02807	34.37667	0.000111	0.00381963
218	2180	1564.516	0	10	1.024902	5.882587	10.30328	35.19257	0.000111	0.003910286
219	2190	1565.568	0	10	1.052246	6.040107	10.5812	36.01653	0.000111	0.004001836
220	2200	1566.647	0	10	1.079346	6.196266	10.85688	36.83384	0.000111	0.004092648
221	2210	1567.754	0	10	1.106445	6.352471	11.13281	37.65187	0.000111	0.004183541
222	2220	1568.887	0	10	1.133789	6.510132	11.41147	38.47803	0.000111	0.004275336
223	2230	1570.048	0	10	1.160889	6.666433	11.68791	39.29758	0.000111	0.004366398
224	2240	1571.236	0	10	1.187988	6.822785	11.96461	40.11791	0.000111	0.004457546
225	2250	1572.245	0	10	1.009033	5.79119	10.14209	34.71471	0.000111	0.00385719
226	2260	1572.939	0	10	0.693604	3.977249	6.95278	25.25936	0.000111	0.002806596
227	2270	1573.66	0	10	0.720703	4.132908	7.225822	26.06885	0.000111	0.002896538
228	2280	1574.407	0	10	0.747925	4.289299	7.500255	26.88246	0.000111	0.00298694
229	2290	1575.183	0	10	0.775146	4.445722	7.774858	27.69657	0.000111	0.003077397
230	2300	1575.985	0	10	0.802368	4.602178	8.049635	28.5112	0.000111	0.003167911
231	2310	1576.814	0	10	0.829468	4.757967	8.32336	29.32271	0.000111	0.003258079
232	2320	1577.671	0	10	0.856689	4.914493	8.598506	30.13844	0.000111	0.003348715
233	2330	1578.555	0	10	0.883911	5.071056	8.873845	30.95473	0.000111	0.003439415
234	2340	1579.466	0	10	0.911011	5.226954	9.148149	31.76796	0.000111	0.003529773
235	2350	1580.404	0	10	0.938232	5.383594	9.423894	32.58546	0.000111	0.003620607
236	2360	1581.37	0	10	0.965454	5.540274	9.699853	33.40359	0.000111	0.003711511
237	2370	1582.362	0	10	0.992554	5.696293	9.974793	34.21871	0.000111	0.003802079
238	2380	1583.382	0	10	1.019775	5.853057	10.2512	35.03816	0.000111	0.003893129
239	2390	1584.429	0	10	1.046997	6.009866	10.52783	35.8583	0.000111	0.003984256
240	2400	1585.503	0	10	1.074219	6.166719	10.80471	36.67915	0.000111	0.004075462
241	2410	1586.605	0	10	1.101318	6.322915	11.08059	37.49705	0.000111	0.004166339
242	2420	1587.671	0	10	1.06665	6.123105	10.72771	36.45086	0.000111	0.004050096
243	2430	1588.683	0	10	1.011841	5.807359	10.17061	34.79924	0.000111	0.003866582
244	2440	1589.663	0	10	0.97998	5.623901	9.847203	33.84044	0.000111	0.003760049
245	2450	1590.611	0	10	0.948364	5.441905	9.52658	32.88989	0.000111	0.003654433

	A	B	C	D	E	F	G	H	I	J
246	2460	1591.528	0	10	0.916626	5.259262	9.205012	31.93654	0.000111	0.003548505
247	2470	1592.413	0	10	0.88501	5.077375	8.884961	30.98769	0.000111	0.003443077
248	2480	1593.266	0	10	0.853149	4.894135	8.562713	30.03232	0.000111	0.003336925
249	2490	1594.088	0	10	0.821533	4.712349	8.243196	29.08505	0.000111	0.003231672
250	2500	1594.878	0	10	0.789795	4.529909	7.922698	28.13487	0.000111	0.003126097
251	2510	1595.629	0	10	0.751343	4.308938	7.534725	26.98465	0.000111	0.002998295
252	2520	1595.588	0	10	-0.04065	-0.2329	-0.4065	4.646489	0.000111	0.000516277
253	2530	1595.57	0	10	-0.01782	-0.10211	-0.17822	4.646489	0.000111	0.000516277
254	2540	1595.575	0	10	0.004639	0.026578	0.046387	4.784011	0.000111	0.000531557
255	2550	1595.603	0	10	0.027466	0.157368	0.274659	5.46077	0.000111	0.000606752
256	2560	1595.653	0	10	0.050049	0.28676	0.500495	6.130303	0.000111	0.000681145
257	2570	1595.725	0	10	0.072632	0.416153	0.726338	6.799858	0.000111	0.00075554
258	2580	1595.821	0	10	0.095337	0.546249	0.953412	7.473066	0.000111	0.000830341
259	2590	1596.211	0	10	0.390259	2.236586	3.905563	16.22529	0.000111	0.00180281
260	2600	1596.59	0	10	0.379639	2.175692	3.799125	15.90974	0.000111	0.001767749
261	2610	1596.957	0	10	0.366089	2.098004	3.663344	15.50719	0.000111	0.001723021
262	2620	1597.309	0	10	0.352539	2.020319	3.527583	15.1047	0.000111	0.0016783
263	2630	1597.648	0	10	0.338867	1.941938	3.390619	14.69864	0.000111	0.001633182
264	2640	1597.973	0	10	0.325317	1.86426	3.254897	14.29626	0.000111	0.001588474
265	2650	1598.285	0	10	0.311646	1.785886	3.11797	13.89032	0.000111	0.001543369
266	2660	1598.583	0	10	0.298096	1.708216	2.982282	13.48805	0.000111	0.001498672
267	2670	1598.868	0	10	0.284546	1.630548	2.846612	13.08582	0.000111	0.00145398
268	2680	1599.139	0	10	0.270996	1.552883	2.710957	12.68365	0.000111	0.001409294
269	2690	1599.396	0	10	0.257324	1.474522	2.574095	12.27789	0.000111	0.00136421
270	2700	1599.64	0	10	0.243774	1.396863	2.438469	11.87581	0.000111	0.001319534
271	2710	1599.87	0	10	0.230103	1.318507	2.301635	11.47013	0.000111	0.001274459
272	2720	1600.086	0	10	0.216553	1.240853	2.166035	11.06812	0.000111	0.001229791
273	2730	1600.289	0	10	0.203003	1.163201	2.030448	10.66615	0.000111	0.001185127
274	2740	1600.479	0	10	0.189331	1.084852	1.89365	10.26058	0.000111	0.001140065
275	2750	1600.828	0	10	0.349243	2.001423	3.494563	15.0068	0.000111	0.001667423
276	2760	1601.522	0	10	0.69458	3.982858	6.962616	25.28852	0.000111	0.002809836
277	2770	1602.217	0	10	0.69458	3.982858	6.962616	25.28852	0.000111	0.002809836
278	2780	1602.95	0	10	0.733032	4.203736	7.350096	26.43728	0.000111	0.002937476
279	2790	1603.703	0	10	0.75293	4.318056	7.55073	27.0321	0.000111	0.003003567
280	2800	1604.433	0	10	0.730347	4.188307	7.323024	26.35702	0.000111	0.002928558

	A	B	C	D	E	F	G	H	I	J
281	2810	1605.141	0	10	0.707642	4.057879	7.094201	25.67863	0.000111	0.002853181
282	2820	1605.826	0	10	0.685059	3.928173	6.866718	25.00421	0.000111	0.002778246
283	2830	1606.488	0	10	0.662354	3.797786	6.638112	24.32647	0.000111	0.002702941
284	2840	1607.128	0	10	0.639648	3.667419	6.40961	23.64903	0.000111	0.00262767
285	2850	1607.745	0	10	0.617065	3.537772	6.182436	22.97553	0.000111	0.002552836
286	2860	1608.339	0	10	0.59436	3.407442	5.95413	22.29867	0.000111	0.00247763
287	2870	1608.911	0	10	0.571777	3.277831	5.727143	21.62572	0.000111	0.002402858
288	2880	1609.46	0	10	0.549072	3.147535	5.499018	20.9494	0.000111	0.002327711
289	2890	1609.987	0	10	0.526489	3.017957	5.272205	20.27697	0.000111	0.002252996
290	2900	1610.491	0	10	0.503784	2.887693	5.044247	19.60114	0.000111	0.002177905
291	2910	1610.972	0	10	0.481201	2.758145	4.817593	18.92918	0.000111	0.002103242
292	2920	1611.173	0	10	0.20166	1.155506	2.017012	10.62631	0.000111	0.001180701
293	2930	1611.239	0	10	0.065552	0.375587	0.655532	6.589941	0.000111	0.000732216
294	2940	1611.296	0	10	0.056519	0.323829	0.565195	6.322119	0.000111	0.000702458
295	2950	1611.343	0	10	0.047363	0.271373	0.473638	6.050682	0.000111	0.000672298
296	2960	1611.381	0	10	0.038452	0.220315	0.384524	5.786486	0.000111	0.000642943
297	2970	1611.411	0	10	0.029297	0.167859	0.29297	5.515056	0.000111	0.000612784
298	2980	1611.431	0	10	0.020264	0.116102	0.202637	5.247246	0.000111	0.000583027
299	2990	1611.442	0	10	0.01123	0.064346	0.112305	4.979438	0.000111	0.000553271
300	3000	1611.444	0	10	0.002075	0.01189	0.020752	4.708012	0.000111	0.000523112
301	3010	1611.437	0	10	-0.00696	-0.03987	-0.06958	4.646489	0.000111	0.000516277
302	3020	1611.421	0	10	-0.01599	-0.09162	-0.15991	4.646489	0.000111	0.000516277
303	3030	1611.396	0	10	-0.02502	-0.14338	-0.25024	4.646489	0.000111	0.000516277
304	3040	1611.362	0	10	-0.0343	-0.19653	-0.34302	4.646489	0.000111	0.000516277
305	3050	1611.288	0	10	-0.07422	-0.42525	-0.74221	4.646489	0.000111	0.000516277
306	3060	1611.2	0	10	-0.08777	-0.50288	-0.87772	4.646489	0.000111	0.000516277
307	3070	1611.099	0	10	-0.10132	-0.58052	-1.01324	4.646489	0.000111	0.000516277
308	3080	1610.98	0	10	-0.11841	-0.67844	-1.18417	4.646489	0.000111	0.000516277
309	3090	1610.631	0	10	-0.349	-2.00002	-3.49212	4.646489	0.000111	0.000516277
310	3100	1610.3	0	10	-0.33093	-1.89645	-3.31114	4.646489	0.000111	0.000516277
311	3110	1609.988	0	10	-0.31274	-1.79218	-3.12897	4.646489	0.000111	0.000516277
312	3120	1609.693	0	10	-0.29468	-1.68862	-2.94806	4.646489	0.000111	0.000516277
313	3130	1609.416	0	10	-0.27649	-1.58437	-2.76595	4.646489	0.000111	0.000516277
314	3140	1609.158	0	10	-0.25842	-1.48082	-2.58509	4.646489	0.000111	0.000516277
315	3150	1608.918	0	10	-0.24023	-1.37657	-2.40304	4.646489	0.000111	0.000516277

	A	B	C	D	E	F	G	H	I	J
316	3160	1608.696	0	10	-0.22217	-1.27303	-2.22223	4.646489	0.000111	0.000516277
317	3170	1608.491	0	10	-0.2041	-1.1695	-2.04144	4.646489	0.000111	0.000516277
318	3180	1608.306	0	10	-0.18591	-1.06526	-1.85945	4.646489	0.000111	0.000516277
319	3190	1608.138	0	10	-0.16772	-0.96104	-1.67748	4.646489	0.000111	0.000516277
320	3200	1607.988	0	10	-0.14978	-0.85821	-1.49797	4.646489	0.000111	0.000516277
321	3210	1607.857	0	10	-0.13147	-0.75329	-1.31481	4.646489	0.000111	0.000516277
322	3220	1607.743	0	10	-0.11353	-0.65047	-1.13533	4.646489	0.000111	0.000516277
323	3230	1607.648	0	10	-0.09521	-0.54555	-0.95219	4.646489	0.000111	0.000516277
324	3240	1607.571	0	10	-0.07727	-0.44273	-0.77273	4.646489	0.000111	0.000516277
325	3250	1607.579	0	10	0.008789	0.050358	0.087891	4.907058	0.000111	0.000545229
326	3260	1607.741	0	10	0.161743	0.926761	1.617643	9.442308	0.000111	0.001049145
327	3270	1607.939	0	10	0.197998	1.134519	1.980369	10.51768	0.000111	0.001168631
328	3280	1608.173	0	10	0.234131	1.341594	2.341951	11.58966	0.000111	0.00128774
329	3290	1608.444	0	10	0.270508	1.550085	2.706068	12.66916	0.000111	0.001407684
330	3300	1608.75	0	10	0.306641	1.757197	3.067849	13.74173	0.000111	0.001526858
331	3310	1608.943	0	10	0.192871	1.105138	1.92907	10.36559	0.000111	0.001151732
332	3320	1608.993	0	10	0.050049	0.28676	0.500495	6.130303	0.000111	0.000681145
333	3330	1609.034	0	10	0.041016	0.235003	0.41016	5.862488	0.000111	0.000651388
334	3340	1609.066	0	10	0.031982	0.183246	0.319826	5.594675	0.000111	0.000621631
335	3350	1609.089	0	10	0.022827	0.13079	0.228272	5.323246	0.000111	0.000591472
336	3360	1609.103	0	10	0.013794	0.079033	0.13794	5.055438	0.000111	0.000561715
337	3370	1609.108	0	10	0.004761	0.027277	0.047608	4.787631	0.000111	0.000531959
338	3380	1609.103	0	10	-0.00427	-0.02448	-0.04272	4.646489	0.000111	0.000516277
339	3390	1609.09	0	10	-0.01331	-0.07624	-0.13306	4.646489	0.000111	0.000516277
340	3400	1609.068	0	10	-0.02246	-0.12869	-0.22461	4.646489	0.000111	0.000516277
341	3410	1609.036	0	10	-0.03149	-0.18045	-0.31494	4.646489	0.000111	0.000516277
342	3420	1608.668	0	10	-0.36853	-2.112	-3.68781	4.646489	0.000111	0.000516277
343	3430	1608.167	0	10	-0.50024	-2.86738	-5.00871	4.646489	0.000111	0.000516277
344	3440	1607.681	0	10	-0.48682	-2.79036	-4.87394	4.646489	0.000111	0.000516277
345	3450	1607.207	0	10	-0.47314	-2.71193	-4.73675	4.646489	0.000111	0.000516277
346	3460	1606.748	0	10	-0.45947	-2.63351	-4.59958	4.646489	0.000111	0.000516277
347	3470	1606.302	0	10	-0.44592	-2.5558	-4.46367	4.646489	0.000111	0.000516277
348	3480	1605.87	0	10	-0.43237	-2.47809	-4.32778	4.646489	0.000111	0.000516277
349	3490	1605.451	0	10	-0.41882	-2.40038	-4.19191	4.646489	0.000111	0.000516277
350	3500	1605.046	0	10	-0.40515	-2.32198	-4.05484	4.646489	0.000111	0.000516277

	A	B	C	D	E	F	G	H	I	J
351	3510	1604.654	0	10	-0.3916	-2.24429	-3.91902	4.646489	0.000111	0.000516277
352	3520	1604.276	0	10	-0.37793	-2.16589	-3.782	4.646489	0.000111	0.000516277
353	3530	1603.912	0	10	-0.36438	-2.08821	-3.64622	4.646489	0.000111	0.000516277
354	3540	1603.561	0	10	-0.35083	-2.01052	-3.51046	4.646489	0.000111	0.000516277
355	3550	1603.224	0	10	-0.33728	-1.93284	-3.37472	4.646489	0.000111	0.000516277
356	3560	1602.9	0	10	-0.32361	-1.85446	-3.23778	4.646489	0.000111	0.000516277
357	3570	1602.588	0	10	-0.31177	-1.78659	-3.11919	4.646489	0.000111	0.000516277
358	3580	1602.058	0	10	-0.5304	-3.04037	-5.31143	4.646489	0.000111	0.000516277
359	3590	1601.359	0	10	-0.69861	-4.00599	-7.00319	4.646489	0.000111	0.000516277
360	3600	1600.665	0	10	-0.69421	-3.98075	-6.95893	4.646489	0.000111	0.000516277
361	3610	1599.975	0	10	-0.68958	-3.95411	-6.91221	4.646489	0.000111	0.000516277
362	3620	1599.291	0	10	-0.68494	-3.92747	-6.86549	4.646489	0.000111	0.000516277
363	3630	1598.61	0	10	-0.68054	-3.90223	-6.82123	4.646489	0.000111	0.000516277
364	3640	1597.934	0	10	-0.67603	-3.8763	-6.77575	4.646489	0.000111	0.000516277
365	3650	1597.263	0	10	-0.67139	-3.84966	-6.72905	4.646489	0.000111	0.000516277
366	3660	1596.596	0	10	-0.66699	-3.82442	-6.68481	4.646489	0.000111	0.000516277
367	3670	1595.933	0	10	-0.66235	-3.79779	-6.63811	4.646489	0.000111	0.000516277
368	3680	1595.275	0	10	-0.65784	-3.77185	-6.59265	4.646489	0.000111	0.000516277
369	3690	1594.622	0	10	-0.65332	-3.74592	-6.54719	4.646489	0.000111	0.000516277
370	3700	1593.973	0	10	-0.6488	-3.71998	-6.50174	4.646489	0.000111	0.000516277
371	3710	1593.329	0	10	-0.64429	-3.69405	-6.45629	4.646489	0.000111	0.000516277
372	3720	1592.689	0	10	-0.63977	-3.66812	-6.41084	4.646489	0.000111	0.000516277
373	3730	1592.054	0	10	-0.63513	-3.64149	-6.36417	4.646489	0.000111	0.000516277
374	3740	1591.423	0	10	-0.63074	-3.61626	-6.31996	4.646489	0.000111	0.000516277
375	3750	1590.805	0	10	-0.61792	-3.54268	-6.19103	4.646489	0.000111	0.000516277
376	3760	1590.212	0	10	-0.59375	-3.40394	-5.94799	4.646489	0.000111	0.000516277
377	3770	1589.631	0	10	-0.5802	-3.32617	-5.81179	4.646489	0.000111	0.000516277
378	3780	1589.065	0	10	-0.56665	-3.24841	-5.67562	4.646489	0.000111	0.000516277
379	3790	1588.512	0	10	-0.55298	-3.16995	-5.53826	4.646489	0.000111	0.000516277
380	3800	1587.972	0	10	-0.53943	-3.0922	-5.40215	4.646489	0.000111	0.000516277
381	3810	1587.447	0	10	-0.52588	-3.01445	-5.26608	4.646489	0.000111	0.000516277
382	3820	1586.934	0	10	-0.51221	-2.93601	-5.1288	4.646489	0.000111	0.000516277
383	3830	1586.436	0	10	-0.49866	-2.85828	-4.99278	4.646489	0.000111	0.000516277
384	3840	1586.239	0	10	-0.19702	-1.12892	-1.9706	4.646489	0.000111	0.000516277
385	3850	1586.333	0	10	0.094604	0.542052	0.946087	7.451349	0.000111	0.000827928

	A	B	C	D	E	F	G	H	I	J
386	3860	1586.441	0	10	0.108154	0.619691	1.081606	7.853122	0.000111	0.000872569
387	3870	1586.563	0	10	0.121704	0.69733	1.217131	8.254912	0.000111	0.000917212
388	3880	1586.698	0	10	0.135376	0.775671	1.353884	8.660342	0.000111	0.00096226
389	3890	1586.847	0	10	0.148926	0.853313	1.489423	9.062174	0.000111	0.001006908
390	3900	1587.01	0	10	0.162476	0.930958	1.62497	9.464031	0.000111	0.001051559
391	3910	1587.186	0	10	0.176147	1.009303	1.761748	9.869534	0.000111	0.001096615
392	3920	1587.391	0	10	0.2052	1.175793	2.052434	10.73133	0.000111	0.00119237
393	3930	1587.608	0	10	0.217041	1.243651	2.170922	11.08261	0.000111	0.001231401
394	3940	1587.83	0	10	0.221436	1.268836	2.214898	11.21299	0.000111	0.001245887
395	3950	1588.056	0	10	0.226074	1.29542	2.26132	11.35061	0.000111	0.001261179
396	3960	1588.286	0	10	0.230591	1.321305	2.306521	11.48462	0.000111	0.001276069
397	3970	1588.521	0	10	0.235107	1.34719	2.351724	11.61863	0.000111	0.001290959
398	3980	1588.761	0	10	0.239624	1.373076	2.396928	11.75265	0.000111	0.00130585
399	3990	1589.005	0	10	0.244141	1.398962	2.442134	11.88667	0.000111	0.001320741
400	4000	1589.254	0	10	0.248657	1.424848	2.487341	12.0207	0.000111	0.001335633
401	4010	1589.507	0	10	0.253296	1.451434	2.533772	12.15835	0.000111	0.001350928
402	4020	1589.765	0	10	0.25769	1.476621	2.57776	12.28876	0.000111	0.001365418
403	4030	1590.027	0	10	0.262329	1.503207	2.624194	12.42642	0.000111	0.001380714
404	4040	1590.294	0	10	0.266846	1.529095	2.669408	12.56047	0.000111	0.001395608
405	4050	1590.565	0	10	0.271362	1.554982	2.714623	12.69452	0.000111	0.001410502
406	4060	1590.841	0	10	0.275757	1.580171	2.758617	12.82495	0.000111	0.001424994
407	4070	1591.122	0	10	0.280518	1.607458	2.80628	12.96625	0.000111	0.001440695
408	4080	1591.411	0	10	0.289063	1.656437	2.891833	13.21989	0.000111	0.001468877
409	4090	1591.762	0	10	0.351563	2.01472	3.5178	15.07569	0.000111	0.001675077
410	4100	1592.114	0	10	0.351563	2.01472	3.5178	15.07569	0.000111	0.001675077
411	4110	1592.452	0	10	0.337646	1.93494	3.378391	14.66239	0.000111	0.001629154
412	4120	1592.78	0	10	0.328613	1.883154	3.287909	14.39413	0.000111	0.001599348
413	4130	1593.1	0	10	0.31958	1.831371	3.197434	14.12591	0.000111	0.001569545
414	4140	1593.41	0	10	0.310425	1.778889	3.105745	13.85407	0.000111	0.001539342
415	4150	1593.712	0	10	0.301514	1.727808	3.016508	13.58952	0.000111	0.001509946
416	4160	1594.004	0	10	0.292358	1.675329	2.924834	13.31773	0.000111	0.001479748
417	4170	1594.287	0	10	0.283325	1.623551	2.83439	13.04959	0.000111	0.001449954
418	4180	1594.562	0	10	0.27417	1.571075	2.74273	12.77785	0.000111	0.001419761
419	4190	1594.827	0	10	0.265137	1.5193	2.6523	12.50975	0.000111	0.001389972
420	4200	1595.083	0	10	0.256226	1.468225	2.563097	12.24529	0.000111	0.001360588

	A	B	C	D	E	F	G	H	I	J
421	4210	1595.33	0	10	0.24707	1.415753	2.471458	11.97361	0.000111	0.001330401
422	4220	1595.568	0	10	0.237915	1.363281	2.379824	11.70194	0.000111	0.001300216
423	4230	1595.797	0	10	0.229004	1.31221	2.29064	11.43754	0.000111	0.001270837
424	4240	1596.017	0	10	0.219849	1.259741	2.199018	11.16591	0.000111	0.001240656
425	4250	1596.28	0	10	0.262817	1.506006	2.629082	12.44092	0.000111	0.001382324
426	4260	1596.616	0	10	0.336182	1.926542	3.363718	14.61889	0.000111	0.001624321
427	4270	1596.952	0	10	0.336182	1.926542	3.363718	14.61889	0.000111	0.001624321
428	4280	1597.288	0	10	0.336182	1.926542	3.363718	14.61889	0.000111	0.001624321
429	4290	1597.624	0	10	0.336182	1.926542	3.363718	14.61889	0.000111	0.001624321
430	4300	1597.96	0	10	0.33606	1.925842	3.362495	14.61526	0.000111	0.001623918
431	4310	1598.297	0	10	0.336182	1.926542	3.363718	14.61889	0.000111	0.001624321
432	4320	1598.633	0	10	0.336182	1.926542	3.363718	14.61889	0.000111	0.001624321
433	4330	1598.969	0	10	0.336182	1.926542	3.363718	14.61889	0.000111	0.001624321
434	4340	1599.305	0	10	0.336182	1.926542	3.363718	14.61889	0.000111	0.001624321
435	4350	1599.641	0	10	0.33606	1.925842	3.362495	14.61526	0.000111	0.001623918
436	4360	1599.977	0	10	0.336182	1.926542	3.363718	14.61889	0.000111	0.001624321
437	4370	1600.429	0	10	0.451294	2.586602	4.517542	18.03962	0.000111	0.002004403
438	4380	1600.991	0	10	0.562622	3.22529	5.635147	21.35298	0.000111	0.002372553
439	4390	1601.554	0	10	0.5625	3.22459	5.63392	21.34934	0.000111	0.002372149
440	4400	1602.116	0	10	0.562622	3.22529	5.635147	21.35298	0.000111	0.002372553
441	4410	1602.679	0	10	0.5625	3.22459	5.63392	21.34934	0.000111	0.002372149
442	4420	1603.097	0	10	0.418457	2.398282	4.188239	17.06334	0.000111	0.001895927
443	4430	1603.463	0	10	0.366089	2.098004	3.663344	15.50719	0.000111	0.001723021
444	4440	1603.825	0	10	0.36145	2.071408	3.616865	15.36939	0.000111	0.00170771
445	4450	1604.182	0	10	0.357056	2.046213	3.572835	15.23885	0.000111	0.001693206
446	4460	1604.534	0	10	0.352417	2.019619	3.52636	15.10107	0.000111	0.001677897
447	4470	1604.882	0	10	0.3479	1.993725	3.481111	14.96692	0.000111	0.001662991
448	4480	1605.226	0	10	0.343384	1.967831	3.435864	14.83278	0.000111	0.001648086
449	4490	1605.564	0	10	0.338867	1.941938	3.390619	14.69864	0.000111	0.001633182
450	4500	1605.899	0	10	0.334351	1.916045	3.345376	14.56451	0.000111	0.001618279
451	4510	1606.229	0	10	0.329712	1.889453	3.298913	14.42676	0.000111	0.001602973
452	4520	1606.554	0	10	0.325317	1.86426	3.254897	14.29626	0.000111	0.001588474
453	4530	1606.875	0	10	0.320801	1.838368	3.20966	14.16215	0.000111	0.001573572
454	4540	1607.191	0	10	0.316162	1.811777	3.163202	14.02442	0.000111	0.001558269
455	4550	1607.502	0	10	0.311646	1.785886	3.11797	13.89032	0.000111	0.001543369

	A	B	C	D	E	F	G	H	I	J
456	4560	1607.81	0	10	0.307129	1.759996	3.072739	13.75622	0.000111	0.001528469
457	4570	1608.112	0	10	0.302612	1.734106	3.02751	13.62213	0.000111	0.00151357
458	4580	1608.369	0	10	0.25708	1.473123	2.571651	12.27065	0.000111	0.001363405
459	4590	1608.216	0	10	-0.1532	-0.8778	-1.53216	4.646489	0.000111	0.000516277
460	4600	1608.072	0	10	-0.14404	-0.82533	-1.44058	4.646489	0.000111	0.000516277
461	4610	1607.937	0	10	-0.13513	-0.77427	-1.35144	4.646489	0.000111	0.000516277
462	4620	1607.811	0	10	-0.12598	-0.72181	-1.25987	4.646489	0.000111	0.000516277
463	4630	1607.696	0	10	-0.1145	-0.65606	-1.14509	4.646489	0.000111	0.000516277
464	4640	1607.88	0	10	0.183838	1.053373	1.83869	10.09764	0.000111	0.00112196
465	4650	1608.082	0	10	0.202026	1.157605	2.020676	10.63718	0.000111	0.001181909
466	4660	1608.302	0	10	0.220215	1.26184	2.202683	11.17677	0.000111	0.001241863
467	4670	1608.541	0	10	0.238281	1.36538	2.383489	11.71281	0.000111	0.001301423
468	4680	1608.797	0	10	0.256348	1.468925	2.564319	12.24891	0.000111	0.00136099
469	4690	1609.072	0	10	0.274536	1.573174	2.746396	12.78872	0.000111	0.001420969
470	4700	1609.364	0	10	0.292603	1.676728	2.927279	13.32498	0.000111	0.001480553
471	4710	1609.675	0	10	0.310791	1.780988	3.109412	13.86495	0.000111	0.00154055
472	4720	1610.004	0	10	0.328857	1.884554	3.290354	14.40138	0.000111	0.001600154
473	4730	1610.351	0	10	0.347046	1.988826	3.472551	14.94154	0.000111	0.001660171
474	4740	1610.716	0	10	0.365112	2.092404	3.653559	15.47818	0.000111	0.001719797
475	4750	1611.033	0	10	0.317139	1.817375	3.172983	14.05342	0.000111	0.001561491
476	4760	1611.285	0	10	0.251831	1.443038	2.51911	12.11488	0.000111	0.001346098
477	4770	1611.559	0	10	0.274292	1.571774	2.743952	12.78147	0.000111	0.001420163
478	4780	1611.856	0	10	0.297119	1.702618	2.972504	13.45906	0.000111	0.001495451
479	4790	1612.176	0	10	0.319702	1.832071	3.198657	14.12953	0.000111	0.001569948
480	4800	1612.518	0	10	0.342285	1.961533	3.424858	14.80015	0.000111	0.001644461
481	4810	1612.883	0	10	0.36499	2.091705	3.652336	15.47455	0.000111	0.001719395
482	4820	1613.271	0	10	0.387695	2.221887	3.87987	16.14912	0.000111	0.001794347
483	4830	1613.681	0	10	0.410278	2.351382	4.106241	16.82024	0.000111	0.001868916
484	4840	1614.114	0	10	0.432983	2.481588	4.333898	17.49518	0.000111	0.001943908
485	4850	1614.57	0	10	0.455566	2.611107	4.560399	18.16668	0.000111	0.00201852
486	4860	1615.048	0	10	0.478271	2.74134	4.788194	18.84202	0.000111	0.002093558
487	4870	1615.549	0	10	0.500854	2.870886	5.014839	19.51396	0.000111	0.002168217
488	4880	1616.073	0	10	0.52356	3.001148	5.242786	20.18975	0.000111	0.002243306
489	4890	1616.619	0	10	0.546265	3.131425	5.470815	20.86579	0.000111	0.002318421
490	4900	1617.171	0	10	0.55249	3.167149	5.533354	21.0512	0.000111	0.002339022

	A	B	C	D	E	F	G	H	I	J
491	4910	1617.724	0	10	0.55249	3.167148	5.533354	21.0512	0.000111	0.002339022
492	4920	1618.277	0	10	0.552979	3.16995	5.538259	21.06574	0.000111	0.002340638
493	4930	1618.827	0	10	0.550537	3.155941	5.513733	20.99303	0.000111	0.002332558
494	4940	1619.378	0	10	0.550537	3.155941	5.513733	20.99303	0.000111	0.002332558
495	4950	1619.929	0	10	0.550659	3.156641	5.51496	20.99666	0.000111	0.002332962
496	4960	1620.479	0	10	0.550537	3.155941	5.513733	20.99303	0.000111	0.002332558
497	4970	1621.03	0	10	0.550659	3.156641	5.51496	20.99666	0.000111	0.002332962
498	4980	1621.58	0	10	0.550537	3.155941	5.513733	20.99303	0.000111	0.002332558
499	4990	1622.131	0	10	0.550659	3.156641	5.51496	20.99666	0.000111	0.002332962
500	5000	1622.682	0	10	0.550537	3.155941	5.513733	20.99303	0.000111	0.002332558
501	5010	1623.232	0	10	0.550659	3.156641	5.51496	20.99666	0.000111	0.002332962
502	5020	1623.783	0	10	0.550537	3.155941	5.513733	20.99303	0.000111	0.002332558
503	5030	1624.333	0	10	0.550537	3.155941	5.513733	20.99303	0.000111	0.002332558
504	5040	1624.884	0	10	0.550659	3.156641	5.51496	20.99666	0.000111	0.002332962
505	5050	1625.434	0	10	0.550537	3.155941	5.513733	20.99303	0.000111	0.002332558
506	5060	1625.985	0	10	0.550659	3.156641	5.51496	20.99666	0.000111	0.002332962
507	5070	1626.536	0	10	0.550537	3.155941	5.513733	20.99303	0.000111	0.002332558
508	5080	1627.025	0	10	0.48938	2.805061	4.899669	19.17251	0.000111	0.002130279
509	5090	1627.038	0	10	0.012573	0.072039	0.125733	5.019248	0.000111	0.000557694
510	0	0	0	0	0	0	0	0	0	0.864318654
511	0	0	0	0	0	0	0	0	0	5.435966379
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