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CONTOUR DATA ACQUISITION SYSTEM FOR ELECTRIC VEHICLE DISTANCE ESTIMATION SYSTEM

Kuew Wai Chew and Chee Ken Leong

Key words: Google Earth's elevation profile, slope angle, battery energy calculations, Contour Positioning System, data acquisition, distance estimation.

ABSTRACT

The conventional distance estimation system only uses a constant speed and a constant level of road elevation to estimate the driving range of a vehicle. This technique leads to low prediction accuracy. In this project, a new estimation technique namely the Contour Positioning System (CPS) for an electric vehicle is proposed. The CPS provides a more reliable estimation of the electric vehicle battery energy usage by taking into consideration additional factors such as road elevation and regenerative braking energy. In order to perform the CPS calculation, first and foremost, the elevation profile of the selected destination must be determined. In this paper, the automated technique to extract the elevation profile i.e. latitude, longitude and altitude was determined by using Google Maps and Google Earth®. This procedure enables the user to obtain accurate road configuration to enable the driver to compute the amount of energy needed to reach the said destination.

I. INTRODUCTION

The Contour Positioning System (CPS) works by extracting the road contour distance and elevation data from the road elevation profiles. These data will be used to generate road contour slope angles, $\angle$ (in °). With the aid of relevant software developed for this purpose, the data obtained from the road profile can be used to estimate the amount of battery energy needed for the said electric vehicle (EV) to complete the journey. For instance, the application of this procedure will indicate to the user that driving 100 km from point A to point B requires 50% of the EV's battery energy. As a result of this computation, the user is in a better position to know if the remaining battery energy is sufficient for this particular EV to reach the chosen destination [4].

The data required to estimate the EV energy consumption is tabulated using Google Earth which provides the road elevation data. The elevation data accuracy is collected at 10 meters per sample. The energy consumption of the vehicle can then be calculated by applying the angle formula as shown in Eq. (5) [9, 11].

Compared to the conventional method of estimation, the proposed method provides higher estimation accuracy as it includes road slope profiles, which drain different amounts of battery energy depending on the degree of the slope. For example, driving up a hill for 100 km in a 10% slope uses more battery energy compared to driving 100 km on a normal 0% straight highway [8, 12]. The parallel multi-channel design in today's GPS receivers produces extremely accurate information. The accuracy of the most standard GPS receivers nowadays are as accurate as within 15 meters on average. Newer GPS receivers with Wide Area Augmentation System (WAAS) capability can improve its accuracy to less than three meters on average. Only certain atmospheric factors and other sources of error such as ionosphere and troposphere delays and signal multipath could affect the accuracy of GPS receivers [2, 5].

II. METHODOLOGY

1. Main System Function

The main function of Contour Positioning System (CPS) is to provide an automated data acquisition method and to perform a better distance estimation method for EVs.

Fig. 1 shows the process flow of the CPS. The numbers indicate the process flow of the system operations.

Fig. 2 shows the main user interface (GUI) while Fig. 3 shows GPS-like interface that indicates the battery energy usage status.

In the experiment conducted, multiple road lines with different contour configurations were used to study the effect of road contour on electric vehicle energy consumption. The

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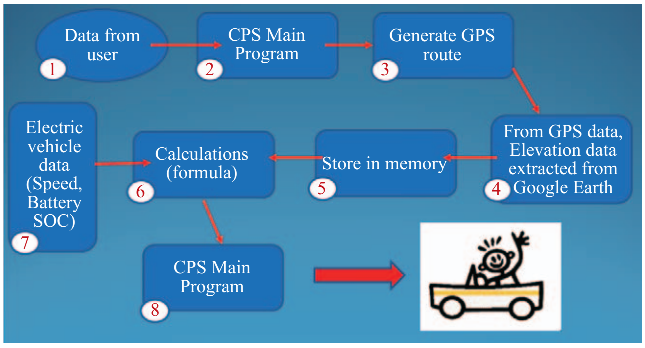

Fig. 1. Flow of process.

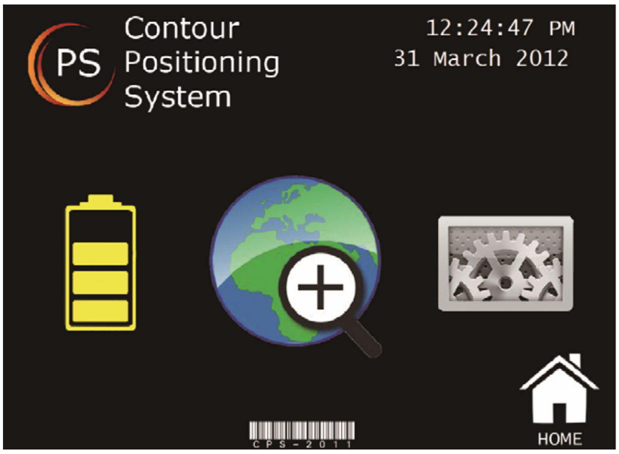

Fig. 2. Flow of Process.

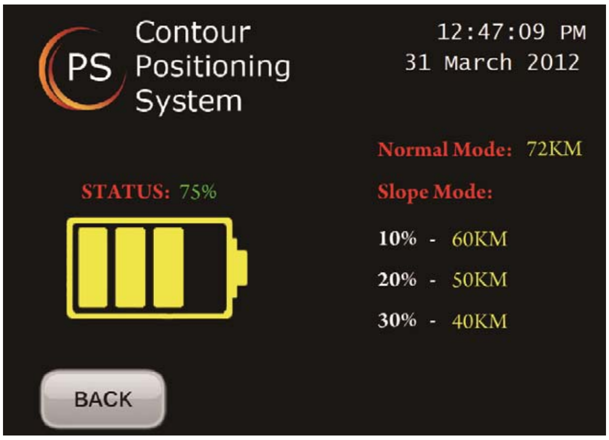

Fig. 3. Battery Monitoring.

routes selected were: normal travelling highway, uphill travelling, and downhill travelling. To use the CPS in an electric vehicle, the user must first determine and select the desired destination. This is the information that is needed from the user. The CPS will detect and pre-calculate the electric car's current position with the GPS antenna and draw the route to the desired destination. The CPS will then extract the distance

Fig. 4. Elevation of a route from Google Earth.

example : Point A → N30 17.017 W97 44.190
Point B → N30 16.595 W97 43.909

Fig. 5. GPS Coordinates.

and elevation profiles to generate the slope percentage data from Google Earth's elevation profile. All these data acquisitions and calculations are acquired in real-time and will be simulated in the background of the CPS software. The data extraction and acquisition processes are performed by a computer-generated system and all the data and information acquired will be stored in a database. 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 insufficient, the CPS system will intelligently advise the user to drive to the nearest charging station [6, 10].

2. Elevation Data Module

Fig. 4 represents the elevation profile extracted in graph form from Google Earth. The CPS system will extract the distance and elevation data along the route line, which represents the starting point of the vehicle and the last point in the graph is the destination. The data extraction is done on every 10 meters per sample.

3. Database Storage Module

Getting all the required data into the database to execute the calculations are important. The data acquired will be stored in algorithm form as the coordinates of the map appear complicated. Fig. 5 shows an example of the coordinates. Storing the data in decimal form will simplify the simulation process using Matlab.

4. Data Generation Module

This method of data generation reduces the processing time of the programme. The algorithm will automatically detect the elevation data obtained. The sample with changing elevation between 10 meters distance will be stored. However, the subsequent sample with no elevation changes will be ignored.

For example, if the selected journey has 100 sets of data where each data containing the longitude, latitude and elevation

Example :	Height	Distance	Action
	10 m	1 KM	store
	10 m	1.1 KM	ignore
	11 m	1.2 KM	store

Fig. 6. Example of data generation module.

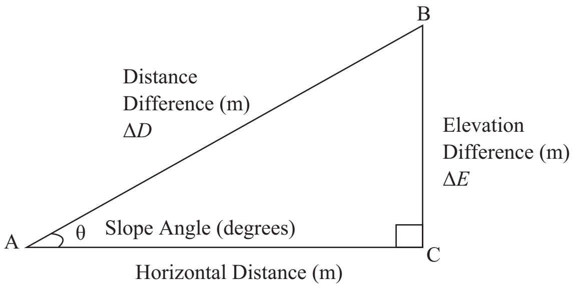

Fig. 7. Relationships between slope angle, distance and elevation difference.

information. The required information to perform the calculation is based on the difference of height between two samples. Once the system detects a height difference of 1 meter, then the system will keep the data. Where else if there is no height difference at the next distance of 10 meters, then the system will erase the data. So the samples of 100 sets of data can be reduced to enhance the processing time.

Fig. 6 shows the example of the data that will be stored or ignored based on the changing of elevation profile.

5. Data Calculation Module

In Fig. 7, the measurement of the distance is taken at every 10 meters. The elevation difference will be taken from a reference of two different elevations. After all the data has been collected, each sample will have a distance and elevation profile stored in an Excel spread sheet. From here, the difference in distance and elevation height is calculated as shown below:

Distance Difference (m) = Current Distance–Previous Distance

$$\Delta D = d_i - d_{i-1} \tag{1}$$

Elevation Difference (m) = Current Elevation–Previous Elevation

$$\Delta E = e_j - e_{j-1} \tag{2}$$

The slope angles in term of degree and percentage are calculated and compared to the measured slope angle obtained from Google Earth using the law of trigonometry formula to get the angle:

$$\theta = \sin^{-1} \frac{\Delta E}{\Delta D} \tag{3}$$

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

Eq. (3) represents the ratio of Elevation Difference over Distance Difference which is to obtain a positive or negative slope. For a downhill slope, the Elevation Difference fraction will return a negative value whereas for an uphill slope, it will return a positive value. The percentage of slope is calculated as the tangent of the angle of inclination times 100 as shown in Eq. (4). It is most commonly used to describe a slope on the road.

The calculations of the vehicle traction torque (and thus power) are a function of velocity, acceleration, and road slope. This function is called the road load equation [1, 3]. From this equation, the value of the traction power, kW operating under any slope angle can be obtained:

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

where,

P = traction power (kgm^{2}s^{-3} = Js^{-1} = W), v = velocity (ms^{-1}), a = acceleration (ms^{-2}), α = slope angle (100sinθ = % slope), m = mass (kg), g = acceleration due to gravity (ms^{-2}), C_{RR} = coefficient of rolling resistance, ρ = density of air (kgm^{-3}), C_D = coefficient of aerodynamic drag, A = frontal area of vehicle (m^2)

Apart from the traction power, the time taken to drive up the hill with different slope angles must also be recorded. To calculate the time (hours) taken for every data sample, the calculations are based on the total power and energy needed to travel at a constant 80 km/h speed up slopes of varying angles of up to 25°. Therefore, the formula to calculate the time taken for each sample is as shown in Eq. (6):

$$\text{Time taken (h)} = \frac{\text{Distance difference (m)}}{\text{80,000 m/h}} \tag{6}$$

Finally, the overall sum of energy usage for each data sample can be calculated using the formula of Eq. (7):

$$\text{Energy usage (kWh)} = \text{Traction power (kW) x Time taken (h)} \tag{7}$$

All these formulae and steps will be used in the Matlab coding and functions for the CPS simulation results [7].

III. RESULTS AND DISCUSSION

The simulation output of current work shows the elevation profile which was extracted from Google Earth. The coordinates are downloaded from the current mapping system database like Garmin Navigation System, Mapking, and others. The coordinates in this simulated experiment are all calculated from Google Maps.

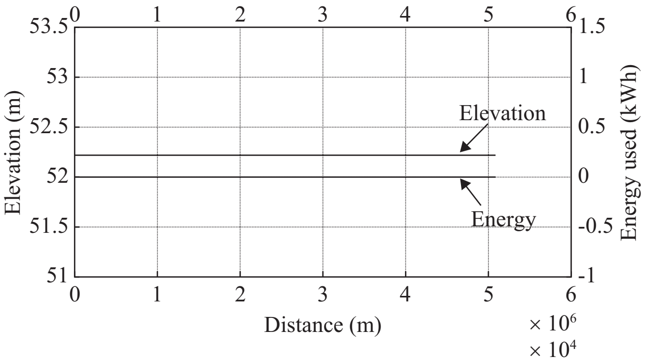

Fig. 8. Graph of Normal GPS system.

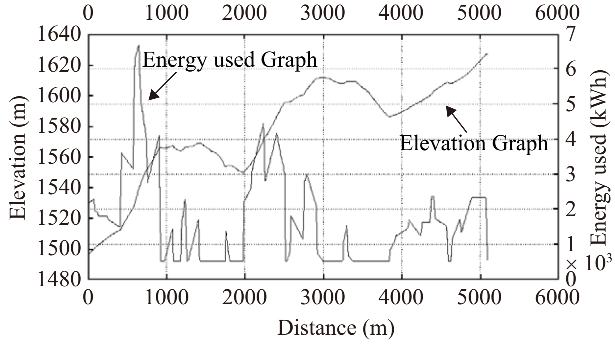

Fig. 10. Energy and elevation profile of 5 KM route uphill.

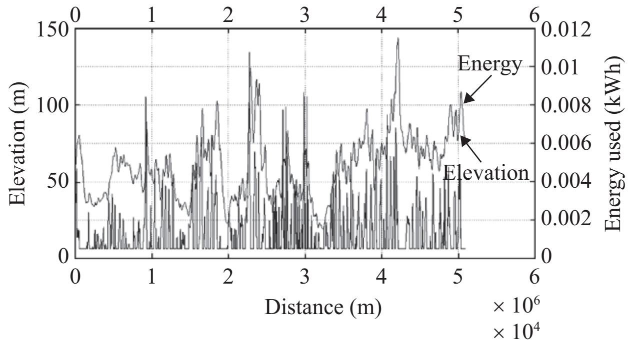

Fig. 9. Elevation and energy profile of 50 KM route.

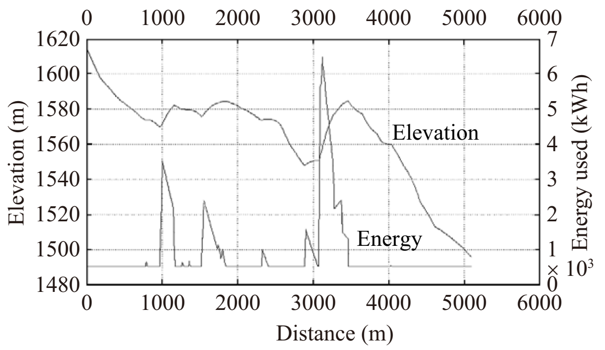

Fig. 11. Energy and elevation profile of 5 KM route downhill.

Based on the database obtained, this model intends to compare the differences between CPS and the current GPS estimation systems. The effect of the contour on battery energy consumption is evaluated. For the first case study as shown in Fig. 8, no contour is being considered in the system's estimation for a route distance of 50 km travelling at 80 km/hr.

Fig. 8 shows that when elevation is not considered, the energy usage is 6.742925 kWh which is 42.41% of the total energy in the vehicle. However, for the same route line, when the elevation profile is added into the simulation (Fig. 9), the total energy usage is 9.589847 kWh which is 60.31% of the total energy in the vehicle. There is about a 20% difference between the two estimation systems.

Another experiment was carried out to validate the contour estimation system which was based on the uphill route of 5 KM. The distance in the experimental study is shortened in order to observe the behaviour of energy usage in a more detailed manner.

Fig. 9 shows that when the contour angle is on an upward climb, the energy needed is greater due to an extra energy needed to climb the slope. In the descent phase the energy usage is minimal because the vehicle is under the free gear movement. The total amount of energy needed to climb the hill route as shown in Fig. 10 is estimated to be 1.051425 kWh which is 6.61% of the vehicle's energy capacity.

Fig. 11 shows the elevation and energy usage profile when the EV is moving downhill of 5 km. It can be observed that the energy usage is lesser when compared to a hill climbing profile. The total amount of energy needed is 0.794818 kWh which is also 5% of the vehicle's energy capacity. Compared to the normal estimation system where the contour is not considered, the uphill energy and downhill energy usage are both at 0.6742925 which is 4.24% of the vehicle's energy capacity.

Table 1 shows the summary of the total energy consumption for three different case studies with and without the consideration of the road elevation. It clearly shows that the CPS method provides a more accurate estimation than the conventional method.

IV. CONCLUSION

The consideration of the contour profile for selected routes offers an additional advantage compared to the existing EV distance estimation method. The reliability of the GPS system can be further enhanced by integrating the CPS function into the current distance estimation technology. The CPS technology was designed and created to solve problems against the conventional distance estimation system. When the electric vehicle is moving up a hill, the current distance prediction method is not accurate and has a higher percentage of error compared to driving on a $\angle 0°$ normal road. This is important

Table 1. Distance Estimation with and without road elevation.

	Energy Used (kWh) (15.9 kWh = 100%)					
	50 KM Highway		Uphill 5 KM		Downhill 5 KM	
Distance estimation without road elevation (kWh)	6.6742925	42.41%	0.674293	4.24%	0.67443	4.24%
Distance estimation with road elevation (CPS) (kWh)	9.589847	60.31%	1.051425	6.61%	1.05142	5%
Percentage Difference		29.67%		35.85%		15.2%

to avoid electric vehicles from being stranded in the middle of a hill slope or road due to the inaccurate distance estimation method.

V. SUGGESTIONS FOR IMPROVEMENT

The regenerative braking generates approximately 5% of the total consumed energy which is sent back to the lithium-ion battery pack. However, this 5% of the regenerative energy is not included in the CPS calculations. This is to provide a small safety buffer into the CPS distance estimation. For example, when the fuel gauge of a mechanical engine car hits the "**E**" mark, the car is capable of travelling an additional 30 to 40 miles even after the "**E**" light illuminates.

Another option to improve the CPS is by using self-learning algorithms. This method will be used when specifications and technical data are unavailable or to reroute to a new driving direction when there is a traffic jam by using Google Maps real-time traffic data.

The CPS assumes that there is constant connection with Google Earth database within the car but this might not be possible all the time. This problem can be resolved by searching for the desired destination and to download the required data when the vehicle is at home or when there is connection to the internet before starting the journey. Beside that, the data acquisition when running under multiple processor platforms is fast and can be done before travelling. Alternatively, the CPS could be connected with a standard navigation system which contains elevation information instead of extracting data from Google Earth's elevation profile which requires internet connection.

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