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Driving support system for electric vehicle considering air-conditioner power consumption based on geographic information system

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Abstract

In recent years, the demand for energy saving is increasing due to the exisiting problems, such as global warming effect caused by the emission of carbon dioxide, and the exhausted use of fossil fuels. As a measure against such environmental and energy problems, in the automotive field, each automobile manufacturer sells various eco cars such as Hybrid Vehicle (HV) and Plug-in Hybrid Vehicle (PHEV) with low carbon dioxide emissions and Electric Vehicle (EV) and Fuel Cell Vehicle (FCV) with no carbon dioxide emissions. The number of such cars is increasing year by year all over the world. Above all, automobile manufacturers are focusing on EV development. However, the EV has some problems, such as short driving distances, long charging times, and large power consumption caused by using the heating system. In addition, the EV has a feature that electric power can be recovered on the downhill while driving because of regenerative brake which is not included in the internal combustion vehicle. Consequently, this work proposes the constructrue of road networks, elevation difference and EV driving data using Geographic Information System (GIS), derivering power consumption estimation formulas for each vehicle type individually. As a result, we have built the smart system to support the EV driving by managing EV power.

Keywords: Geographic Information System (GIS), Electric Vehicle (EV), navigation system

1. Introduction

The scale of energy consumption depends on the level of human life and economic activity, and a large amount of fossil fuel has been used to stimulate economic activity, supporting and our human life. According to the IPCC 5th Assessment Report, the global average temperature has risen by 0.85 °C in the period from 1880 to 2012, and will continue to rise in the future. From the huge observation data and the result of climate simulation, the theory that the atmospheric accumulation of anthropogenic greenhouse gases (based on carbon dioxide) accompanied by fossil fuel consumption is the major cause of global warming is strongly considered [1]. The transport sector accounts for about 20% of Japan's total carbon dioxide emissions, which is one of the major sources of carbon dioxide emmission. Under such circumstances, Japanese government is working to achive a goal of increasing the proportion of next-generation vehicles, which account for approximately 2% of the current sales volume of new vehicles, to apporoximately 50% in order to reduce carbon dioxide emissions while linking it to the technological strength and competitiveness of Japan's automobile industry. Such movements are becoming active mainly in developed countries all over the world. In particular, the EV has attracted great attention. Since the EV does not use fossil fuels and not emit carbon dioxide while driving, thus it is expected to be used as one of the solutions in solving the environmental problems. On the other hand, the EV has some problems, such as short driving range, long charging time, insufficient charging infrastructure, and large power consumption of air conditioners compared with international comsumption vehicles at the present

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moment. Furthermore, since the EV has a motor used as a power source, the power consumption can be recovered by regenerative braking, and it depended on the traveling speed (e.g., when traveling on a high road or in traffic jam).

In order to use the EV effectively in the future, we believe that it will be effective to build a system that supports driving to manage the amount of power used while driving. In this system, it is necessary to understand whether the users can reach the destination with the current battery level before driving, or if they can not reach, where is the suitable route for charging. Therefore, our research team takes into consideration the features of EV and derives a power consumption estimation equation for each vehicle type individually by processing road networks, elevation differences, and EV travel data using Geographic Information System (GIS). As a result, we have built a smart system to manage electric power, supporting EV driving. We assumed that this driving support system will eventually be installed in a car manufacturer's genuine navigation system.

Among them, a heating system consumes a large amount of power, which greatly affects the amount of available power for EV driving. So, in this research, we examine the influence, which the heating system affects to the amount of power used while driving. Furthermore, from the verified results, we add a new term to estimate the power consumption of heating to the power consumption estimation formula derived in previous researches and propose the novel method to estimate the power consumption while driving considering the use of heating system.

2. System Construction

2.1. GIS utilization overview

Geographic Information System (GIS) is a technology for modeling the real world on a computer. When modeling the real world, it uses the layer in which features such as buildings and roads, and events including population distribution and congestion information are classified according to themes.The real world is modeled by superimposing the layers. The basic concept is shown in Fig. 1 [3]. Although GIS can model the real world using layers, it has the following two features. It is possible to understand the distribution of data on one map, and to understand the relationship with other data on two maps [4]. From the above features, information can be visualized, searched, analyzed, and transmitted in GIS by using data arrangement, integration, and management. Finally, it is possible to support the user's decision-making.

The data in GIS is called geospatial information (geospatial data). Geospatial information can be divided into two types: that is raster and vector, depending on how it is abstracted and represented in the real world. The raster type is composed of cells arranged in a grid of rows and columns. It is suitable for representing continuous data which does not have clear boundaries. Examples include aerial photographs and elevation data. Fig. 2 shows an example of the raster type.

In Fig. 2, it is possible to visually and intuitively grasp the elevation difference by color coding. On the other hand, the vector type is a data format, which is suitable for representing features (e.g., building, road and so on), in the real world. It is expressed by three elements of 1 point, 2 line, 3 polygon [5]. Fig. 3 shows an example of the vector type. Fig. 4 shows an image of three elements of the vector type.

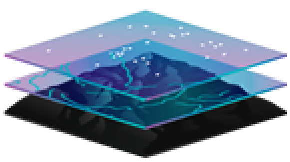

Fig. 1. The model of a variety of layers

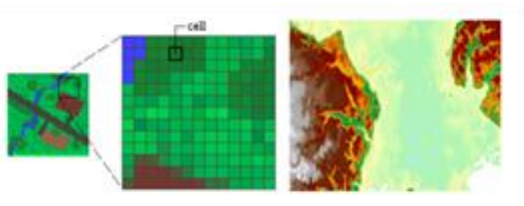

Fig. 2. The overview of the raster data

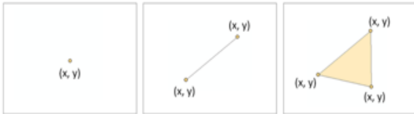

Fig. 3. The overview of the vector data

2.2. How to get the driving data

We have used the Nissan LEAF (model: ZE1) in our experiments to conduct our previous research. Fig. 4 shows a picture of the vehicle. In order to obtain the LEAF's driving data, we use the Android application called Leaf Spy Pro and OBD Link Mx as a Bluetooth communication terminal for OBD2 connection. By using these, it is possible to acquire information such as the battery level, latitude, longitude, driving speed and the like. Data can be acquired approximately every 2-3 seconds [6]. Based on the travel data obtained in this method, the amount of power consumption necessary while driving is estimated.

Fig. 4. The picture of the studied electric vehicle

2.3. Outline of driving support system using power comsumption estimation formula based on GIS

Although it is necessary to estimate the power consumption required for the driving route when building the EV driving support system, in our research, we define power consumption estimation formula and calculate/estimate the power consumption required for driving. The formula is shown in (1), and the proposed concept is shown in Fig. 5.

$$W = \frac{x}{a} + W(h) \tag{1}$$

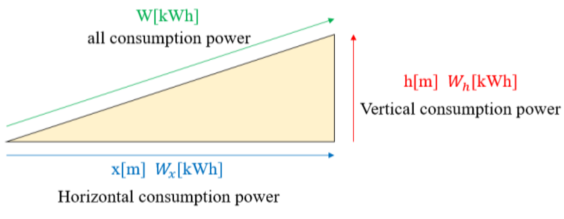

Fig. 5. The outlinone of the proposed power consumption estimation

In equation (1), it represents the horizontal electric expenses [m/kWh] corresponding to the fuel consumption of the internal combustion vehicle. x represents the travel distance [m]. Also, W(h) represents the power consumption necessary for vertical movement [kWh], and h represents the elevation difference [7]. The EV uses a motor as a power source. Unlike an internal combustion vehicle, the EV has the feature to recover electric energy through the negenerataive brake. By using GIS, the data of driving distance and elevation difference can be easily acquired. It is possible to present effective information to the user by combining the GIS and estimated electric energy value for the driving calculated from this fomula. From the research results, the uphill and downhill power consumption estimation formulas for Nissan LEAF (type: ZE1) are as shown in formulas (2) and (3) [8].

Uphill
$$W = \frac{x}{8740} + 0.0054h \tag{2}$$

Downhill
$$W = \frac{x}{8740} + 0.0046h \tag{3}$$

In addition, the EV has the feature that the electric expenses change greatly depending on the driving speed. Therefore, the power consumption estimation formula is derived by dividing General road, Highway, Crowded and Traffic jam.

2.4. The experimental results

One of the disadvantages of EV is that it can not use the engine exhaustion heat for heating like internal combustion vehicles, so it need to separate a heat source by itself. Therefore, the amount of energy required for heating is increased. As a result, the driveable range is shortened. In this paper, we aim to estimate the power consumption required for heating and for supporting the user's decision-making. While the EV was traveling, we operated the heating and measured the power consumption at that time. Fig. 6 shows an example of the measurement result in the case of cooling system. Fig. 7 shows in the case of heating system at the studied time. Fig. 6 confirmed that the power consumption of the cooling was largely disturbed. On the other hand, Fig. 7 confirmed that the power consumption of the heating was not so much disturbed. Fig. 8 shows that the data of driving speed is superimposed on Fig. 6. Fig. 9 shows that data of driving speed is superimposed on Fig. 7.

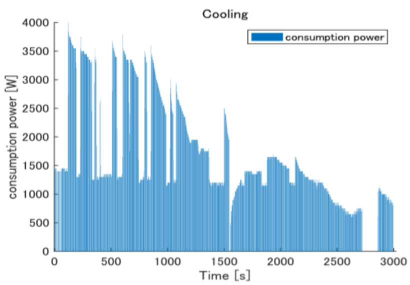

Fig. 6. The consumption power on the cooling system

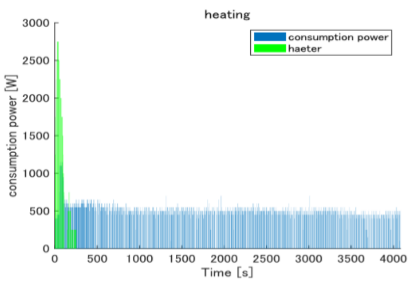

Fig. 7. The consumption power on the heating system

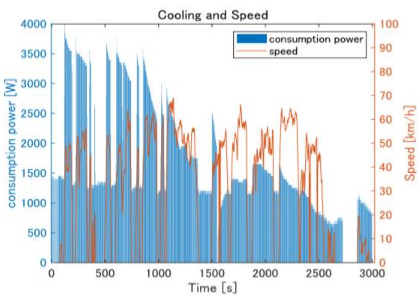

Fig. 8. The consumption power based on the cooling system and speed

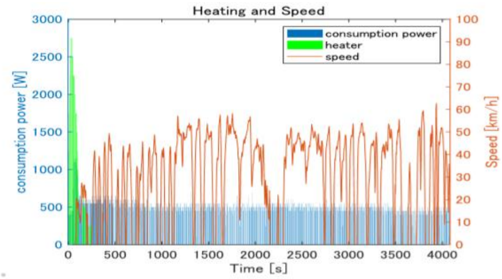

Fig. 9. The consumption power based on the heating system and speed

Fig.8 confirmed that in the case of cooling, it represented the correlation between tha data of the driving speed and power consumption on the cooling. On the other hand, Fig.9 confirmed that in the case of heating, alhough the power consumption after the start was temporarily large, thereafter it became almost constant. Therefore, in this paper we focused on the power consumption of the heating system.

2.5. The definition and the calculation of the air conditioner consumption coefficient

By considering the long time heating data averagly, the power consumption on heating can be estimated simply. We defined a new term representing the power consumption on heating in regards to the the power consumption formula. The formula is shown in (4).

$$W = \frac{x}{a} + W(h) + W(t) \tag{4}$$

In this formula, t represents Time [min], and c is the average power consumption [kWh/min] for heating per minute.

Moreover, the formula for calculating the value of c is shown in (5).

$$c = \frac{(all\ consumption\ power\ on\ heating)\ -\ (all\ consumption\ power\ off\ haeting)}{time} \tag{5}$$

The formula (6) shows the value of c calculated by (5). The formula (7) and (8) show the power consumption estimation formula based on heating.

$$c = 0.01507 \tag{6}$$

uphill

$$\mathrm{W} = \frac{x}{8740} + 0.0054h + 0.01507t \tag{7}$$

downhill

$$\mathrm{W} = \frac{x}{8740} + 0.0046h + 0.01507t \tag{8}$$

2.6. The comparison of the error rate

In this section, we describe the error rate of estimated value and measured value by using the studied system. Table 1 shows the comparison of the measured value with heating and the estimated value without heating. In addition, Table 2 shows the comparion of the measured and estimated values on heating.

Table 1.The comparison of the measured value with heating and estimated value without heating

No.	Measured value with heating [kWh]	Estimated value without heating [kWh]	Error rate[%]
①	4.65	3.99	-14.2
②	6.45	5.45	-15.5
③	8.87	7.15	-19.3

Table 2. The comparison of the measured and estimated values with heating

No.	Measured value with heating [kWh]	Estimated value with heating [kWh]	Error rate[%]
①	4.65	5.09	8.59
②	6.45	6.95	7.27
③	8.87	8.78	-0.95

Table 1 and Table 2 show that the error rates are decreased by introducing the new term for estimating the heating power consumption.

2.7. The verification of the contribution rate

The EV has a special feature that the amount of power consumption necessary while driving varies greatly based on the driving speed, road situations (e.g., highway, crowded, and traffic jam), and heating system. Therefore, it is necessary to evaluate whether the driving speed, road attributes, and traffic jam are considered the estimation. We calculated the estimated value with heating and without heating while driving, and examined the contribution rate of heating for the total power consumption required for driving. The formula (9) shows the first definition of the contribution rate.

$$(the\ contribution\ rate) = \frac{(heating\ consumption\ power)}{(all\ consumption\ power\ on\ heating)} \times 100 \qquad (9)$$

By using (9), we examined the contribution rate based on six possible patterns s follows: (1) general road, (2) general road with the averaged speed of 60km/h, (3) general road with the averaged speed of 40km/h, (4) highway, (5) crowded road, and (6) shortest distance. Table 3 shows the simulation results.

Table 3.The estimated value and contribution rate per six driving modes

No.	Driving mode	Time [min]	Without heating [kWh]	With heating [kWh]	Heater consumption [kWh]	Contribution rate [%]
①	General road	95	8.51	9.94	1.43	14.4
②	General road(40km/h)	105	8.51	10.09	1.58	15.7
③	General road(60km/h)	70	8.51	9.56	1.05	11
④	Highway	60	9.26	10.16	0.9	8.9
⑤	Crowded road	210	10.3	13.46	3.16	23.5
⑥	Shortest distance	130	7.7	9.66	1.96	20.3

Table 3 shows that the estimated values without heating (in cases (1)-(3)) are the same value since it is assumed that driving speed does not affect the changes of electric expenses when driving on the same general road, but the estimated values with heating are different. In the case of (2), the contribution rate is about 15.7%, which is larger than 14.4% the case (1). It is assumed that the increase of driving time caused the increase in the contribution rate. On the other hand, in the case (3), the contribution rate is about 11%, which is smaller than the case (1). It is assmed that the decrease of driving time caused the decrease in the contribution rate. In the case (4), the contribution rate is about 8.9%, which is smaller than the case (3). It is assumed that the decrease of driving time and the deterioration of electric expenses (due to the increase of driving speed on the highway) caused the decrease in the contribution rate. Also, in the case (5), the contribution rate is about 23.5%, which is the largest value. This result shows that the increase of the driving time and the deterioration of electric expenses (due to the decrease of driving speed in crowded roads) cause the increase of heating power consumption in EV.

This simulation results confirmed that the contribution rate was significantly different based on the driving patterns. Therefore, this work showed the superiority of estimating the power consumption of EV heating by using the variable t [min].

2.8. Program description for EV users

It is important for safty driving to know how far the EV user can reach with the amount of power remaining before or during driving. Therefore, we believe that the estimation and reachable area from the remaining power visualization are significant information. These features are made by using the software called ArcGIS's Network Analyst. Figs. 10 and 11 show the estimated maps of reachable areas within 13.0 kWh from the starting point.

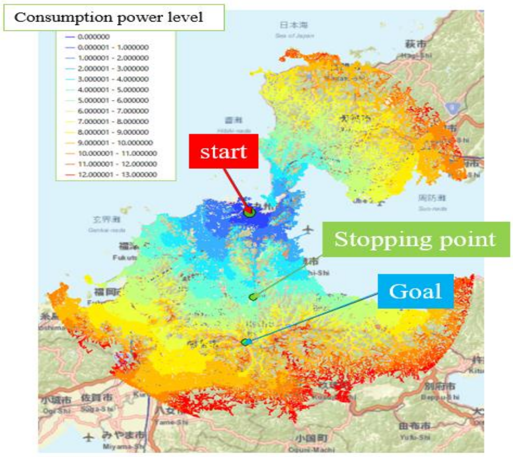

Fig. 10. The reachable area without heating

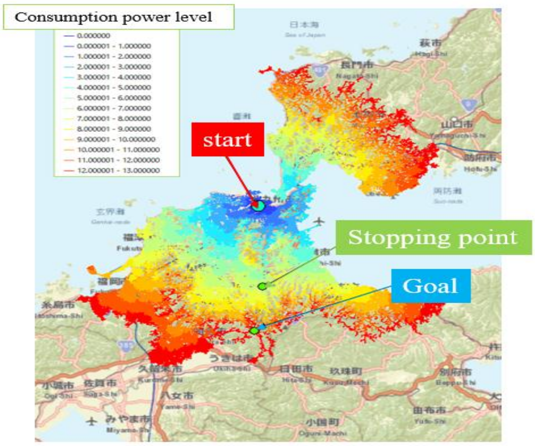

Fig. 11. The reachable area with heating

Figs.10 and 11 confirm that the estimated maps of reachable areas with and without heating are largely different. In these maps, the color label is changed every 1kWh (blue indicates low power consumption and red indicates high power consumption). Using these maps, it easy to visually recognize for EV users. This application enables the user to check the required amount of power consumption for driving to any point/area.

In the conventional navigation system, since the reachable area was estimated from (electric expenses) × (remaining power amount), only rough information could be presented to the user. However, our driving support system combining power consumption estimation formula and Geographic Information System enables the estimation based on the EV's features.

3. Conclusion

In this paper, we vertified the influence on the amount of electric power used for driving with or without heating, and added a new term for the electric power consumption of heating to the power consumption estimation formula presented in the previous studies. Therefore, this paper aimed to propose a new method to estimate the amount of energy consumption used for driving based on the use of heating system.

Although the power consumption of the heating in EV's increases temporarily after the driving start, it tends to become the constant value after that. Therefore, we calculated the power consumption of the heating by considering the averaged data measured over a long time. By combining the power consumption estimation formula and GIS, it is possible to estimate the power consumption required when using the heating system. Moreover, it is possible to provide users with important information according to the driving mode, and selection of the optium route for driving. In addition, we created the estimated maps of the reachable areas in cases with and without thr heating system.

In the future, we will propose a method to estimate the power consumption of the cooling system developing a system using real time data while driving. Finally, we will aim to introduce an existing EV navigation system equipped with the proposed application. Also, in recent years, automatic driving technology has attracted great attention and it is known to be very compatible with EV. Therefore, we will develop a system that also assumes an application for autonomous driving vehicles.

Conflict of Interest

The authers declare no conflict of interest.

Author Contribution

All auther concuted the research; Hiroki Iwai analyzed the data and wrote the paper; all authers had approved the final version.

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