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Energy-efficient route-planning path selection for Electric vehicles

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Abstract: The whole world is now facing the disastrous consequences of Global Warming. To overcome the damaging effects of global warming UN Kyoto Protocol was developed. All the participating countries must replace conventional vehicles with electric vehicles, promote mass transportation and avoid energy wastage. Electric vehicles have received significant attention from international leaders due to rise in pollution from conventional vehicles and the running down of crude oil stocks. Electric vehicle is powered by electric motor that uses energy as fuel stored in batteries as electric charge. Conventional vehicles path selection from source to destination is very simple. A conventional vehicle often chooses a path between the source and destination with a shortest distance or minimum journey time. However, electric cars have a limited capacity of battery energy. It takes a long time to recharge batteries, so the path selected for electric vehicles must be energy-efficient. Electric Vehicle path selection becomes a very challenging task. This paper compares features of different traditional algorithms used to find shortest path and also identified algorithms that can be used to find energy-efficient path for electric vehicle. The battery pack energy utilization model is developed for electric vehicle that use vehicle dynamics, traffic information, and road grade information. The energy-efficient path for an electric vehicle is determined using bellman ford algorithm.

Keywords: Global Warming; Electric vehicles; path selection; traditional algorithms; bellman ford algorithm

1. Introduction

In the late 19th century, the average temperature on the earth's face was elevated by around 1.62°F (0.9°C). This increase in temperature is due to an increase in emissions of greenhouse gases into the atmosphere [1]. For the first time in recorded history, CO2 levels exceeded 400 ppm in 2013 as Figure 1 shows. This is crucial to realise that 95% of global transport energy is derived from fossil fuels, principally petrol and diesel. Vehicles on the road create 50% emissions of the entire transport sector, which contributes 7% of the global CO_2 emissions [2]. The whole world is now facing the disastrous consequences of Global Warming. Glaciers are retreating everywhere in the world. Ice is melting in the Arctic, Antarctic, Greenland, Himalayas and across other regions of the world. To overcome the damaging effects of global warming UN Kyoto Protocol was developed in 1997 [3]. All the participating countries have a mandatory reduction in coal-fired power generation, increase nuclear power, replace conventional vehicles with electric vehicles, promote mass transportation and avoid energy wastage.

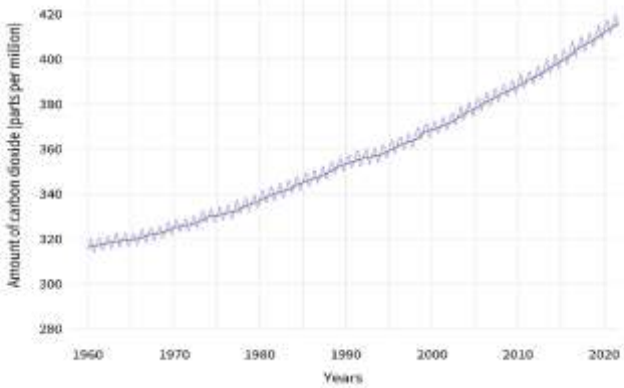

Figure 1 Atmospheric CO_2 level from 1960 to 2020.

Electric vehicles have received significant attention from international leaders due to rise in pollution from conventional vehicles and the running down of crude oil stocks. Enforcement of rigorous emission standards in conventional automobiles has done nothing to offset the effect of the constantly rising demand for more vehicles. Another drawback of the Internal Combustion Engines (ICE) is that their manufacturing process consumes more resources and causes more industrial pollution because their design is more complex than electric vehicles. Anyway, conventional vehicles cannot go on forever because of the depleting reserves of fossil fuels [2].

The Japanese Toyota debuted the "Prius," the first large-scale commercial car manufactured and marketed in 1997 in Japan as a hybrid car. At the San Francisco International Motor Show in November-2006, Tesla Motors revealed the extremely sporty Tesla Roadster. Nissan also launched its new electric car in the year 2008, called the LEAF ("Leading, Environmentally Friendly, Affordable, Family Car") [4]. In the year 2017, the first tender to buy electric cars in India was won by Tata Motors through Energy Efficiency Services Limited (EESL).

EV is propelled by a combination of electric motor and transmission system, EV withdraws power from pack of batteries or a fuel cell installed in the vehicle. An electric motor that uses energy as a fuel is driven by an EV, which is stored in the battery pack. EV charging is different from fueling conventional vehicles. EV’s are recharged at home, office parking, or public charging stations. Most of the time, electric vehicle charging takes place at the owner’s home overnight in a garage. Electric vehicle can be plugged into a power socket in the garage [5]. EV offers maximum fixed energy, which is not enough to travel from source to destination, depending on the size of the battery pack, so EV may require recharging during the journey. Recharging an EV is very time-consuming process, EV owners may have to face long charging queue at a charging station [6]. Conventional vehicles can have many different paths from source to destination. Traditional vehicles pick a road between the source and destination which has a shortest path or minimum journey time. But for EV the path picked must have minimal energy usage. So, path selection becomes a challenging task for EV’s. An extension of the shortest path algorithm was built using open-source libraries to determine the energy-efficient path between source and destination [7]. Traditional algorithms like Dijkstra are not designed for EV’s. Traditional algorithms measure the shortest distance or minimum traveling time between source and destination. These algorithms work fine for conventional vehicles. But for Electric vehicles it does not work as many other parameters are taken into consideration for finding the energy-efficient path between source and destination. An algorithm is proposed to determine energy-efficient path, it also incorporates EV battery constrains [8]. In order to overcome the inability to find path using traditional algorithms a reliable shortest path (RSP) technique is proposed that make use of the K-shortest path algorithm [9]. Sometimes energy-efficient path is longer than the shortest path, which may not be accepted by the user. So, a user-friendly path planning method for EV is introduced that can trade between the eco-friendly path and shortest path [10].

EV has some unique features such as a regenerative braking system; it generates power during breaking and moving down the hill and stores this power into batteries for later use. Other parameters such as elevation change, friction, speed limits, auxiliary loads, traffic, and driving style greatly impact the performance of Electric Vehicle. Electric Vehicle path planning is a very challenging task. This paper compares traditional algorithms used to find the shortest path and demonstrates how these algorithms can be used to find energy-efficient paths for EVs. This paper's main contribution is to develop an energy consumption model for EV based upon traffic information, road grade and vehicle dynamics. This model is used to find energy-efficient path for EV.

2. Experimentation

2.1. Traditional algorithms

Comparison of different traditional algorithms available to determine efficient path from source to destination for conventional vehicles in Table 1. From Table 1, we can conclude that all the traditional algorithms do not support negative weighted edges. Only Bellman ford, Johnson and Floyd Warshall algorithm supports negative weighted edges.

To determine energy-efficient path from source to destination for EV negative weighted edges plays a vital role, As EV have regenerative breaking property, Regenerative breaking system helps to recharge the batteries whenever the breaks are applied to slow down the EV or vehicle moving down the hill. Because of the regenerative braking, the amount of energy consumed by an EV to travel between two points is sometimes less than the amount of energy regenerated by the regenerative braking system. The total cost of travelling between two points becomes negative. This negative cost is assigned to the edge of graph. So more than one edges may have negative cost from source to destination. So, algorithms that support negative edge are suitable to determine energy-efficient path from source to destination for EV.

Table 1 Comparison of traditional algorithms used to find shortest path.

Algorithm	**Complexity V= Vertices, E=Edges**	**Approach**	**Negative weight Edge Support**
Dijkastra	$O(v^2)$	Greedy	×
Suurballe	$O(E + V \log V)$	Greedy	×
Bellman Ford	$O(v^3)$	Dynamic	✓
Fredman	$O(E + V \log V)$	Greedy	×

Johnson	$O(V^2 \log V + VE)$	Dynamic	✓
Viterbi	$O(v^2)$	Dynamic	×
Floyd Warshall	$O(v^3)$	Dynamic	✓

2.2. Energy consumption model

EV's are very different from conventional vehicles that consume petrol and diesel as fuel and their energy consumption is calculated in kilometers per liter or miles per gallon. An energy consumption model for EV was proposed [11]. The energy consumption of an electric vehicle is the sum of powers at the battery terminal. As per principles of vehicle dynamics for any vehicle, the sum of forces acting on a moving vehicle is given by (i).

$$\boldsymbol{F_{total}} = \boldsymbol{F_{roll\_resistance}} + \boldsymbol{F_{rode\_grade}} + \boldsymbol{F_{air\_resistance}} + \boldsymbol{F_{acceleration}} \qquad \text{(i)}$$

Rolling Resistance is the force against the motion of the EV. It is the force between tires of EV and road. Road Grade is a measure of slope. It indicates how much road inclined from horizontal. It might be negative as vehicle moving downhill. Air Resistance of EV is the resistance against air. Acceleration force is the force acting on moving EV.

A more detailed equation given in (ii), it makes use of different parameters of EV to calculate the sum of different force acting on EV. Where M is mass of electric vehicle in Kg, A_f is Front area of electric vehicle, g is Gravitational acceleration, δ is Rotational inertia factor, f_r is Rolling resistance, P_a is Air mass density, a is acceleration in m/s^2, C_d is Aerodynamic drag coefficient. i is road grade.

$$\boldsymbol{F_{total}} = (M \times g \times f_r) + (M \times g \times i) + (0.5 \times P_a \times C_d \times A_f) + (M \times \delta \times a) \qquad \text{(ii)}$$

Total power required to move the EV with velocity 'V' is given by equation (iii). As EV's have regenerative breaking system that generates power when vehicle is moving down the hill or while pressing the breaks. This power is used to recharge the batteries of the EV, it can be calculated using equation (iv). Where ∝ indicates the percentage regenerative energy that regenerated by motor of electric vehicle. Value of ∝ (0<∝<1). Finally, the total power consumed by EV can be calculated using equation (v).

$$\boldsymbol{Power_{out}} = \boldsymbol{F_{total}} \times \boldsymbol{V} \qquad \text{(iii)}$$

$$\boldsymbol{Power_{regenrative}} = \propto \times \boldsymbol{Power_{out}} \qquad \text{(iv)}$$

$$\boldsymbol{Power_{total}} = \boldsymbol{Power_{out}} + \boldsymbol{Power_{regenrative}} \qquad \text{(v)}$$

2.3. Road network model

A road network model is created (Figure 2) in the form of graph G = (V, E) to determine the energy-efficient path for electric vehicles. |V| is a set of vertices, and |E| is set of edges representing road segments. Let 'l_{ij}' is the length of the road segment between two vertices 'i' and 'j'. The Road network model can be represented using (vi).

$$\mathbf{RM = (S, l_{ij}, G, V_z, C)} \qquad \text{(vi)}$$

The road network model contains a set of vertices S, l_{ij} length of road segment and G represents different road grades, V_z is zero flow speed of the electric vehicle and C is the maximum vehicle capacity for each road grade as given in table 2.

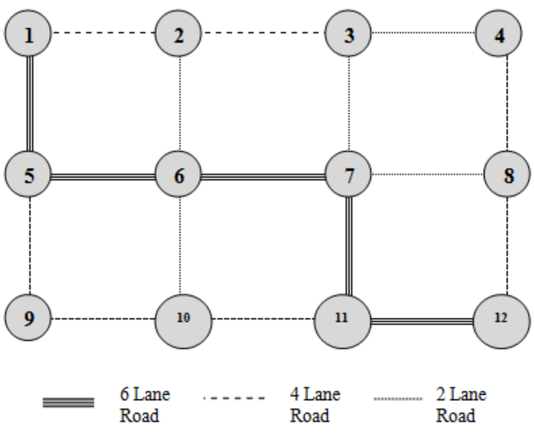

Figure 2: Road network map.

Table 2 Road grade, zero flow speed and traffic capacity.

Road Grade (G)	Zero Flow Speed V_z (km/h)	Maximum Traffic Capacity C (Vehicle/h)
6 lane road	60	8000
4 lane road	50	6000
2 lane road	40	3000

Real time information of the road traffic can be used to calculate the real time speed as given in (vii) of the electric vehicle and time taken to travel a road segment, different road segments have different volumes of traffic depending upon the road grade of the that segment.

$$S = \frac{V_z}{1+\frac{K_{t-1}}{C}} \qquad \text{(vii)}$$

3. Results and Discussions

3.1. Energy-efficient path selection

Energy consumption of the electric vehicle is different for different road grades given in table 4. Energy consumption for different road grades is calculated using equations (v) and (vii) along with typical parameters of the electric vehicle given in table 3. These parameters are used to calculate the power required to move an EV between two nodes.

Table 3 Typical parameters of electric vehicle.

M	Mass of electric vehicle in Kg	**1521kg**
g	Gravitational acceleration	**9.8 m/s²**
$\boldsymbol{f}$	Rolling resistance	**0.005**
$\boldsymbol{\rho}$	Air mass density	**1.275 kg/m³**
$\boldsymbol{C_x}$	Aerodynamic drag coefficient	**0.25**
A	Front area of electric vehicle	**2.25 m²**
$\boldsymbol{\delta}$	Rotational inertia factor	**1**

Table 4 Electric vehicle energy consumption road grade wise.

Road Grade	Energy Consumption
6 lane road	3.21 kwh
4 lane road	3.20 kwh
2 lane road	3.19 kwh

Bellman ford algorithm is applied to determine the shortest path for an electric vehicle between source and destination based upon travel time and energy consumption. The path that will take minimum travel time from source node 1 to destination node 12 is shown in figure 3 (red color path). Path is 1->5->6->7->11->12. The same source and destination are used to find the energy-efficient path on the same road map using the bellman ford algorithm shown in figure 4. Path is 1->2->6->10->11->12. So experiment results clearly show that an energy-efficient path is completely different from a path having the shortest travel time.

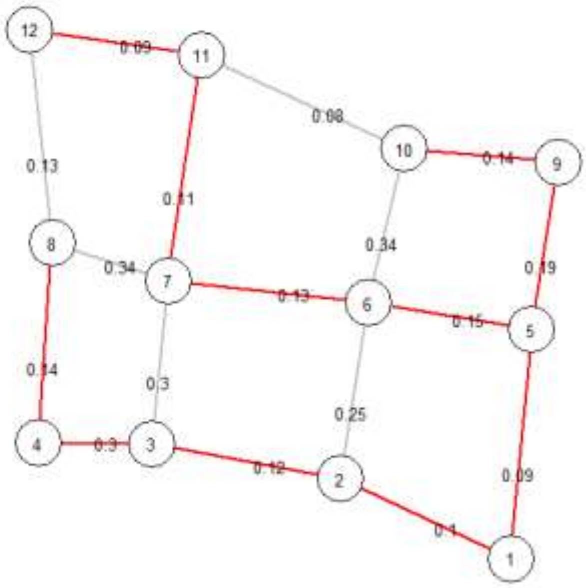

Figure 3: Traveling path having minimum time.

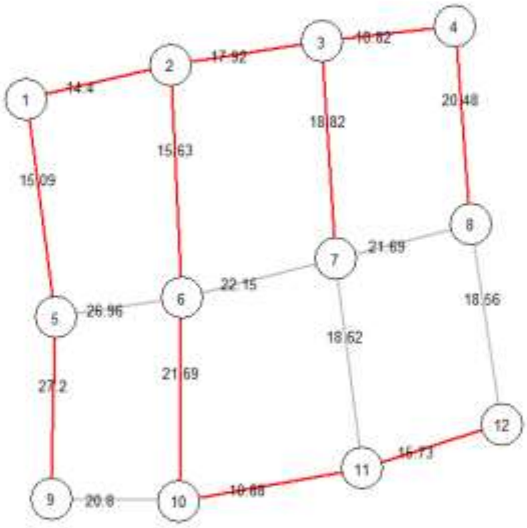

Figure 4: Energy efficient path.

4. Conclusions

The energy-efficient path selection for EV using conventional algorithms was examined and compared based on the features. The comparison shows that algorithms supporting negative edge weight are suitable for finding the energy-efficient path between source and destination for an EV. An energy utilization model for an EV is proposed that uses different configuration parameters of EV along with road traffic information and road grades. Bellman ford algorithm is used to compute shortest path and the energy-efficient path between the same pair of source and destination. It was proved that energy-efficient path for an EV cannot be same as shortest path for conventional vehicle.

References

[1] Hansen, J., Ruedy, R., Sato, M., & Lo, K. (2010). Global surface temperature change. Reviews of Geophysics, 48(4).

[2] Hannappel, R. (2017, August). The impact of global warming on the automotive industry. In AIP Conference Proceedings (Vol. 1871, No. 1, p. 060001). AIP Publishing LLC.

[3] Bose, B. K. (2010). Global warming: Energy, environmental pollution, and the impact of power electronics. IEEE Industrial Electronics Magazine, 4(1), 6-17.

[4] Sulzberger, C. (2004). An early road warrior: electric vehicles in the early years of the automobile. IEEE Power and Energy Magazine, 2(3), 66-71.

[5] Yilmaz, M., & Krein, P. T. (2012). Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles. IEEE transactions on Power Electronics, 28(5), 2151-2169.

[6] Alesiani, F., & Maslekar, N. (2014). Optimization of charging stops for fleet of electric vehicles: A genetic approach. IEEE Intelligent transportation systems magazine, 6(3), 10-21.

[7] Artmeier, A., Haselmayr, J., Leucker, M., & Sachenbacher, M. (2010, September). The shortest path problem revisited: Optimal routing for electric vehicles. In Annual conference on artificial intelligence (pp. 309-316). Springer, Berlin, Heidelberg.
[8] Sachenbacher, M., Leucker, M., Artmeier, A., & Haselmayr, J. (2011, August). Efficient energy-optimal routing for electric vehicles. In Twenty-fifth AAAI conference on artificial intelligence.
[9] Shen, L., Shao, H., Wu, T., Lam, W. H., & Zhu, E. C. (2019). An energy-efficient reliable path finding algorithm for stochastic road networks with electric vehicles. Transportation Research Part C: Emerging Technologies, 102, 450-473.
[10] Storandt, S. (2012, November). Quick and energy-efficient routes: computing constrained shortest paths for electric vehicles. In Proceedings of the 5th ACM SIGSPATIAL international workshop on computational transportation science (pp. 20-25).
[11] Abousleiman, R., & Rawashdeh, O. (2015, June). Energy consumption model of an electric vehicle. In 2015 IEEE transportation electrification conference and expo (ITEC) (pp. 1-5). IEEE.