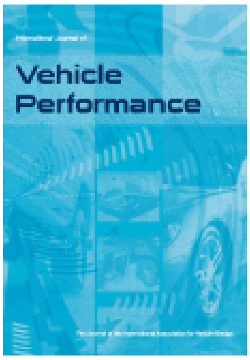

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A new method to determine electric vehicle range in real driving conditions

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Abstract: The main goal of this paper is the development of a method that allows a control system to determine the electric vehicle (EV) driving range within the highest precision. The methodology has been developed for real driving conditions taking into account not only the kind of driving but also the road characteristics and the driving operational mode. Battery capacity change with discharge has been considered for the available energy. A simulation process has been developed to reproduce the driving characteristics of a daily trip considering the dynamic conditions and vehicle characteristics such as size, shape and mass. Five different driving modes are included in the study, acceleration, deceleration, constant speed, ascent and descent. Specific software has been developed to predict electric vehicle range under real driving conditions as a function of the characteristic parameters of a daily trip.

Keywords: electric vehicle; driving range; driving conditions simulation; real conditions modelling; software design.

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1 Introduction

In present days, one of the main worries of electric vehicle manufacturers is the range of autonomy, either for pure electric vehicles (EV), plug-in electric vehicles (PHEV) or hybrid electric vehicles (HEV). Many studies have been devoted to this goal by public and private research institutions, providing a database that is used by car manufacturers (https://ev-database.org/cheatsheet/range-electric-car, https://insideevs.com/reviews/344001/https://insideevs.com/reviews/344001/, https://www.edmunds.com/car-news/electric-car-range-and-consumption-epa-vs-edmunds.html#chart). Private companies develop their own tests to determine the driving range of an electric vehicle; an updated database can be found in the public website (Aidi and Yousra, 2020). The driving range of an electric vehicle, however, is not a constant value, as it depends on many factors like driving mode (Scurtu et al., 2019; Andaloro et al., 2015), road type (Mruzek et al., 2016), traffic environment (Li et al., 2021), battery ageing (Çeven et al., 2020; Yao et al., 2021), etc.; therefore, the real value currently differs from car manufacturer data.

Driving range depends on battery capacity, provided the aforementioned factors remain unchanged, thus the higher capacity the longest range. Nevertheless, battery capacity is not constant since it evolves with discharge rate and power demand, resulting in a variable autonomy and driving range. The effects of the discharge rate have been widely studied by many authors analysing the different factors that modify the battery capacity due to operating conditions (Zhou et al., 2020; Armenta-Déu et al., 2019; Yang et al., 2019; Huang and Lai, 2019; Ewert et al., 2021).

Although driving range has been improved in the last years, it continues being the most important challenge researchers and industry have to make electric vehicles competitive. Comparing driving ranges with internal combustion engine vehicles, the ones for EV still are low, especially in interurban routes. Despite the urban routes are relatively well covered by today's EV autonomy, a more adaptive performance of EV car batteries to real conditions can enlarge the driving range, thus the time of a single use.

2 Driving cycle protocol

Among the many driving tests for EV, four are the most relevant, NEDC, WLTP, FTP-75 and JC08. The first two have been developed for the European market while the FTP-75 and JC08 are for the American and Japanese one. Some differences arise when comparing one to another; New European Driving Cycle (NEDC) is mainly devoted for urban routes, although it includes an extra urban driving cycle (EUDC); however, the protocol does not match the real driving conditions in current days, as it is considered too conservative (Meinrenken et al., 2020). The FTP-75 is also a driving cycle protocol firstly developed for urban routes, but updated for highway driving (HWFET), aggressive driving (SFTP US06) and optional air conditioning tests (SFTP SC03) (https://dieselnet.com/standards/cycles/ftp_sc03.php Access online 10/07/2021). This test is more realistic than NEDC as it includes some of the today's driving mode in modern cities and developed countries.

FTP-75 test, however, is developed for the American Standard driving conditions, whose speed limits in many states are a little bit more conservative than European ones (https://dieselnet.com/standards/cycles/ftp75.php). Japanese JC08 cycle (https://dieselnet.com/standards/cycles/jp_jc08.php) is even more conservative than FTP- 75 as speed limit is concerned; besides, the cycle duration is too short for the modern driving time in a current day; therefore, it does not represent a real picture of a single mode of EV driving for today's drivers. Finally, WLTP (World Harmonized Light- duty Vehicle Test Procedure), shows up as a solution to fulfil the real requirements of power demand for an EV in modern society, especially for interurban routes; although more realistic than the NEDC, the WLTP protocol slightly differs from real driving conditions, since the driving conditions under which the protocol run is based on average driving conditions, which are not always real (https://wiki.unece.org/display/trans/WLTP + Technical + Reports; https://ecgassociation.eu/wp-content/uploads/2019/10/19.10-WLTP-briefing-paper-v3-Draft-v1-Web.pdf).

In summary, due to that specific driving mode the people adopt there is not a unique driving protocol that could match the driving conditions; therefore, it is wise to develop an adaptive model that can be applied to changes in the driving mode as vehicles and road conditions evolve. This can also be applied to urban routes where traffic regulations may affect the speed limits or time interval of driving before stopping.

3 Modelling

The development of the new driving cycle modelling is based on the consideration that the daily cycle is made up of a group of five steps, normal running at constant speed, acceleration, deceleration, ascending and descending road. These five steps are complemented with the corresponding stops, when necessary, and the regenerative breaking process during descend, if any.

The daily cycle, then, must be divided into these five steps, plus the corresponding stops, to match the global time dedicated to the daily urban route. It is assumed daily cycle is repeated day after day with no exception. Based on statistical data and the current way of driving in a big city, for which the model has been developed, a specific time has been assigned to every step, no matter when the step has happened in the day. By doing so, we have grouped all times a step is produced in a single event, thus simplifying the model development.

At every step, the car has driven a certain distance given by the dynamic conditions of driving; the sum of all distance should give the global distance of a daily route. In case a specific cycle is being reproduced this global distance should match the standard distance of the tested cycle.

4 Methodology

The project should develop a software that allows the user to know the remaining driving distance by setting up the driving conditions from a menu on the control panel. This menu should include the different options that correspond to the driving mode and type of journey. Every option will claim for the related algorithms that control the driving process, and how they influence the performance of the battery, thus the amount of extracted charge and energy, and consequently the driving range.

5 Theoretical background

The autonomy of an electric vehicle depends on the energy consumption rate and on the battery capacity that supplies energy for propelling the vehicle. The energy of the battery is directly related to its operational voltage through the expression:

$$\xi = C\,V \tag{1}$$

where ξ is the energy, C is the capacity, and V is the voltage.

Electric vehicle energy consumption can be obtained from the demanded power and time of operation, where the power is given by the classical expression:

$$P = Fv \tag{2}$$

where F is the global force and v is the vehicle speed.

Since an electric vehicle does not maintain constant speed at all times, equation (2) should be transformed into:

$$P = F < v > \tag{3}$$

where <*v*> is the average value of the speed that can be obtained from the following equation:

$$<v>=\frac{1}{t_2-t_1}\int_{t_1}^{t_2} v(t)\mathrm{d}t \tag{4}$$

The speed distribution is not often known as it depends on driving conditions and driving mode, which can be considered variable randomly.

Global force can be expressed as:

$$F = ma + kv^2 + \mu mg + mg\sin\beta \tag{5}$$

where *m* is the mass of the vehicle, *a* the acceleration, *k* the drag coefficient, *v* the vehicle speed, μ the friction factor with the road, and β the slope of the road.

The first term of the right hand of the equation corresponds to the inertial effects, the second is the drag force due to the wind, third term refers to the friction between the vehicle tyres and the road, and the last term accounts for the force in tilted sections of the road.

If we consider a daily trip we should divide the whole route into segments since the driving conditions, speed, acceleration, and tilt are not constant at all times. In such a case, global force must be expressed as:

$$F=\sum_{i=1}^{n}F_i=\sum_{i=1}^{n}\left(ma_i+k_iv_i^2+\mu_i mg+mg\sin\beta_i\right) \tag{6}$$

To simplify the analysis, a constant friction factor can be considered, assuming the type of road is the same for the whole trip. Drag coefficient depends on type of flow, thus on Reynolds' number, given by the equation:

$$\mathrm{Re}=\left(vL_{eq}/\nu\right) \tag{7}$$

The parameter L_{eq} represents the equivalent length of the cross section of the vehicle, which is directly dependent on its shape and size, and ν is the kinetic viscosity of air.

If we assume there is not a significant change in the vehicle speed along the route, the Reynolds' number can be considered constant since the air's viscosity is also constant provided there is not a sudden change in air's temperature, and because shape and size of the vehicle are not modified, L_{eq} can be considered constant.

In these conditions, drag coefficient is also constant, and the global force expression adopts the form:

$$F=\sum_{i=1}^{n}\left(ma_i+kv_i^2+\mu mg+mg\sin\beta_i\right) \tag{8}$$

Power and energy demand to propel the vehicle are supplied by the battery, thus $\xi_{EV}=\xi_{bat}$. Using equation (1) and converting mechanical power in equation (3) into energy:

$$CV = F <v> \Delta t \tag{9}$$

Now replacing equations (3) and (8) into equation (9):

$$CV = \sum_{i=1}^{n}\left[\left(ma_i + kv_i^2 + \mu mg + mg\sin\beta_i\right) < v_i > \left(\Delta t\right)_i\right] \tag{10}$$

where the time interval, Δt_i, is the duration of every segment of the trip

Battery voltage decays as charge is extracted, thus the voltage cannot be taken as a constant in equation (10). To determine the battery voltage at every time we should know the evolution with time; for lithium batteries, which are the most widely used in electric vehicles, the voltage decay follows a linear pattern that can be expressed as:

$$V_i = V_o - s(DOD)_i \tag{11}$$

where V_o is the initial voltage at fully charge state, s is the slope of the voltage decay line, and DOD is the depth of discharge.

The parameter V_o depends on the type and structure of the battery, and is currently given by the manufacturer; the slope is obtained from the technical data sheet of the battery, also provided by the manufacturer, or experimentally determined. Although the slope of the voltage decay line for any kind of batteries depends on the discharge rate, in the case of lithium batteries there is only a slight influence, thus the parameter s can be considered constant between certain limits.

Applying the aforementioned condition, we deduce that:

$$s = \frac{V_o - V_{off}}{100} \tag{12}$$

where V_{off} represents the cut-off voltage of the battery

Depth of discharge is defined as the fraction of charge extracted from the battery related to its global capacity. Global capacity, also called nominal capacity, is the charge a battery can deliver, from fully charge state until completely discharged, for a reference time, most of the times 20 h, a value that is usually provided by the manufacturer.

Since the battery voltage decays for a time interval corresponding to a segment of the trip, equation (10) must be expressed in the following form:

$$C\left(V_o - V_{off}\right) = \sum_{i=1}^{n}\left[\left(ma_i + kv_i^2 + \mu mg + mg\sin\beta_i\right) < v_i > \left(\Delta t\right)_i\right] \tag{13}$$

Applying equation (11), and considering that for $V_i = V_{off}$, $(DOD)_i = (DOD)_{max}$:

$$Cs\left(DOD\right)_{\max} = \sum_{i=1}^{n}\left[\left(ma_i + kv_i^2 + \mu mg + mg\sin\beta_i\right) < v_i > \left(\Delta t\right)_i\right] \tag{14}$$

Battery capacity is also dependent on the type of discharge rate; for a lithium battery, this dependence has been found (Martínez-Arriaga et al., 2020):

$$C_i = C_n\left(f_i / f_{ref}\right) \tag{15}$$

C_i represents the real capacity of the battery for a specific discharge rate, while C_n is the nominal capacity at fully charge state. The f-factor is the so called *capacity correction factor*, and is obtained from the expression (Armenta-Déu et al., 2019):

$$f_i = 0.9541\left(t_i\right)^{0.0148} \tag{16a}$$

$$f_{ref} = 0.9541\left(t_{ref}\right)^{0.0148} \tag{16b}$$

where the reference discharge time, t_{ref}, is currently taken as 20 h, and the discharge time, t_i, can be calculated from the following equation:

$$t_i = \left(C_n / I_i\right) \tag{17}$$

Combining equations (15)–(17):

$$C_i = C_n\left(I_{ref} / I_i\right)^{0.0148} \tag{18}$$

Because a daily trip can be represented as a combination of several segments, each one having specific dynamic conditions, average speed, acceleration, slope of the road, the battery capacity cannot be assumed to have a unique value; therefore, equation (10) must be applied to every single segment of the daily trip, resulting:

$$C_n\left(\frac{I_{ref}}{I_i}\right)^{0.0148}\left[V_o - s(DOD)_i\right] = \left(ma_i + kv_i^2 + \mu mg + mg\sin\beta_i\right) < v_i > \left(\Delta t\right)_i \tag{19}$$

Applying equation (12):

$$\begin{aligned} &\frac{C_n}{100}\left(\frac{I_{ref}}{I_i}\right)^{0.0148}\left(V_o\left[100-(DOD)_i\right] + V_{off}(DOD)_i\right) \\ &\quad = \left(ma_i + kv_i^2 + \mu mg + mg\sin\beta_i\right) < v_i > \left(\Delta t\right)_i \end{aligned} \tag{20}$$

In general terms, the mathematical equation for the DOD coefficient can be expressed as:

$$\left(DOD\right)_i = Q_i / C_i \tag{21}$$

where Q_i accounts for the extracted charge from the battery that can be obtained from:

$$Q_i = I_i\left(\Delta t\right)_i \tag{22}$$

Since the discharge process is continuous, the DOD coefficient must be expressed in terms of the cumulative charge extracted from the battery, thus:

$$\left(DOD\right)_i = \sum_{j=1}^{i}\frac{Q_j}{C_j} \tag{23}$$

Using equations (18) and (22):

$$\left(DOD\right)_i = \frac{1}{C_n\left(I_{ref}\right)^{0.0148}}\sum_{j=1}^{i}\left(I_j\right)^{1.0148}\left(\Delta t\right)_j \tag{24}$$

Now replacing in equation (20):

$$\frac{1}{100}\left(\frac{1}{I_i}\right)^{0.0148}\left[100V_oC_n\left(I_{ref}\right)^{0.0148}-\left(V_o-V_{off}\right)\sum_{j=1}^{i}\left(I_j\right)^{1.0148}\left(\Delta t\right)_j\right]$$
$$=\left(ma_i+kv_i^2+\mu mg+mg\sin\beta_i\right)<v_i>\left(\Delta t\right)_i \tag{25}$$

Equation (25) represents the energy balance at every single segment of a daily trip for the electric vehicle.

6 Electric vehicle driving range

The range of an electric vehicle, based on a daily trip, can be defined as the maximum number of days the electric vehicle can use the battery before recharging is required. According to this definition we can obtain the electric vehicle autonomy as:

$$\mathrm{T}_{aut}=\xi_{bat}/\xi_{day} \tag{26}$$

Where the daily energy consumption, ξ_{day}, is given by:

$$\xi_{day}=\frac{1}{100}\left(\frac{1}{I_i}\right)^{0.0148}\left[100V_oC_n\left(I_{ref}\right)^{0.0148}-\left(V_o-V_{off}\right)\sum_{j=1}^{i}\left(I_j\right)^{1.0148}\left(\Delta t\right)_j\right] \tag{27}$$

Using the definition of battery energy from equation (1):

$$\mathrm{T}_{aut}=\frac{CV}{\frac{1}{100}\left(\frac{1}{I_i}\right)^{0.0148}\left[100V_oC_n\left(I_{ref}\right)^{0.0148}-\left(V_o-V_{off}\right)\sum_{j=1}^{i}\left(I_j\right)^{1.0148}\left(\Delta t\right)_j\right]} \tag{28}$$

Nevertheless, the battery capacity and voltage are not constant as discharge process is going by; therefore, the CV product must be expressed as:

$$CV=\sum_{i=1}^{n}C_iV_i=\sum_{i=1}^{n}\left[C_n\left(I_{ref}/I_i\right)^{0.0148}\right]\left[\frac{V_o\left[100-\left(DOD\right)_i\right]+V_{off}\left(DOD\right)_i}{100}\right] \tag{29}$$

Replacing in equation (28):

$$\mathrm{T}_{aut}=\frac{\sum_{i=1}^{n}\left[C_n\left(I_{ref}/I_i\right)^{0.0148}\right]\left\{V_o\left[100-\frac{1}{C_n\left(I_{ref}\right)^{0.0148}}\sum_{j=1}^{i}\left(I_j\right)^{1.0148}\left(\Delta t\right)_j\right]+V_{off}\frac{1}{C_n\left(I_{ref}\right)^{0.0148}}\sum_{j=1}^{i}\left(I_j\right)^{1.0148}\left(\Delta t\right)_j\right\}}{\left(\frac{1}{I_i}\right)^{0.0148}\left[100V_oC_n\left(I_{ref}\right)^{0.0148}-\left(V_o-V_{off}\right)\sum_{j=1}^{i}\left(I_j\right)^{1.0148}\left(\Delta t\right)_j\right]} \tag{30}$$

Equation (30) provides the range of the electric vehicle, on a daily trip basis, as a function of characteristic parameters of the battery, nominal capacity, C_n, reference discharge current, I_{ref}, open circuit voltage, V_o, and cut-off voltage, V_{off}, as well as a function of the operational parameters, discharge current, I_i, and time of running, $(\Delta t)_i$.

It can be noticed that discharge current adopts two forms, I_i and I_j, both corresponding to the same parameter. The difference in the sub-index notation corresponds to the cumulative effect when calculating the depth of discharge coefficient, where the discharge current sub-index is noted as *j* to distinguish from an individual segment of the discharge for which the sub-index is noted as *i*.

7 Simulation process

To evaluate the autonomy of an electric vehicle a simulation process has been developed; the simulation is based on a model that reproduces the performance of the real prototype. To do so, the characteristics of the electric vehicle as well as of the battery must be known in order to establish the modelling values; these characteristics are, on the side of the vehicle, the mass, the operational voltage of the electric engine, the wheel radius, the model of the vehicle, type of tyres and road, and on the side of the battery, the battery energy, nominal capacity, open circuit and cut-off voltage, and reference discharge time.

To simulate the performance of the battery, the aforementioned characteristics are essential, since they are variables of the mathematical expression that determines the available power and energy of the battery for the specific operational conditions.

Vehicle mass is used to obtain the global force (equation (5)) while operational voltage of the electric engine sets up the battery voltage. The wheel radius, combined with the angular speed of the engine, is used to determine the vehicle speed, one of the parameters involved in the calculation of the global force; the model of the vehicle determines its shape and size, thus the drag coefficient. Finally, the type of tyres and road establishes the friction factor, which also intervenes in the determination of the global force.

Vehicle speed and acceleration, below the limits imposed by the manufacturer, are subject to the driver's decision, which means they depend on the driving mode. Three different driving modes have been considered, aggressive, moderate or normal and gentle. The three modes are distinguished by the acceleration rate, whose values are indicated in Table 1.

Table 1 Acceleration values for the different driving modes

Driving mode	*Acceleration* (m/s^2)	*t* (s) [0–100 km/h]
Aggressive	3.50	6.9
Moderate/Normal	2.50	11.1
Gentle	1.50	18.5

The values presented in Table 1 match, within a low margin error, the current values of combustion engine vehicles that are commercialised in present days.

First category with the highest acceleration rate corresponds to luxury and expensive vehicles, with very powerful engines, but not accessible to most of the drivers. Moderate or normal acceleration range includes the majority of urban utility vehicles, compact, saloon or SUV. Gentle acceleration category is devoted for small cars with low power engines and very high mileage rate.

To facilitate driver's decision, the simulation will give the option to users to decide whether or not the default option is chosen. Default option is automatically selected by the control system according to set up parameters that looks for an optimum performance of the battery service for a specific vehicle and trip. The default option, in our simulation, has been assigned to the moderate/normal acceleration rate. Driver, however, can enter the advanced mode, where the control system lets choosing which acceleration rate is preferred, thus rearranging the calculation according to the driver's selection.

The simulation has the goal of reproducing real driving situation based on an urban daily trip. The trip has been divided into five segment categories, normal driving, acceleration and deceleration process, and ascent or descent road. Normal driving has been configured to maintain vehicle speed constant, while acceleration or deceleration processes correspond to segments where the vehicle speed is increasing or decreasing due to mechanical action on the vehicle dynamic state, which means pressing or releasing the accelerator pedal. Ascent and descent segments are those where the slope of the road exceeds a threshold, either positive or negative.

Drag coefficient and friction factor are currently set up according to vehicle mass range; the typical values have been represented in Table 2.

Table 2 Drag coefficient and friction factor for EV's

Mass (kg)	K	μ
1000–2500	0.578	0.15
3000–3500	1.458	0.15

The average vehicle speed is calculated by the classical expression of the kinematics:

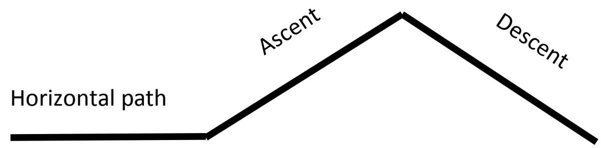
$$v = d/t \tag{31}$$

where d is the travelling distance and t is the time. These two variables are retrieved by the Google Maps application. However, when our software determines the route to be taken, it will not determine all the fractions of the route in the form of the five algorithms. In fact our software will transcribe the path in the form of:

- a horizontal path (which takes into account normal walking, acceleration and deceleration)
- an ascending part
- a descending part

The path can then be simplified as represented in Figure 1.

Figure 1 Schematic representation of a daily trip



It is important to know that on Google Map there is no access to descent or ascent percentages, and consequently this application does not allow us to have all the necessary information; therefore, Google Maps application will only be used to define the route and determine the distance and duration of the trip from which we can calculate the average speed.

To determine the inclination of the road, different solutions are possible, but the preferred solution is the inclinometer (https://witmotion.aliexpress.com/store/; https://www.analog.com; https://www.te.com/; https://www.ctisensors.com). This one will allow to obtain the inclination of the daily route taken by the user in order to determine the final angle of ascent and descent.

In our model we have chosen this last system because of its major sensitivity to changes in the road tilt. Distance is being calculated through the classical equation:

$$d = vt \tag{32}$$

where v is the average speed of the vehicle and t is the time. The vehicle speed is calculated using the expression (https://aprendecienciaytecnologia.wordpress.com/; https://x-engineer.org/automotive-engineering/chassis/vehicle-dynamics/calculate-wheel-vehicle-speed-engine-speed/):

$$v = \frac{\pi D \omega r_g}{(1000/60)} \tag{33}$$

where D is the wheel diameter, ω is the engine rotational speed, in *rpm*, and r_g is the gear box ratio. These three parameters are currently known from the vehicle manufacturer data sheet.

In case the trip segment is made up of up and down sections, we have to group all ascent sections in one as well as for the descent; in such a case, the equivalent tilt angle of the road, either ascent or descent is given by:

$$\beta = \frac{\sum_{i=1}^{n} d_i \beta_i}{\sum_{i=1}^{n} d_i} \tag{34}$$

where the sub-index i corresponds to the number of section within the segment, and n is the number of sections.

8 Software development

To simulate the performance of a prototype vehicle under specific driving conditions, it is necessary to develop a software program that reproduces the different steps of the daily driving. This program commands a control system that receives information of the variables intervening in the daily driving.

Driver can get useful information from his or her daily driving route as:

- the energy spent in percentage (%)
- the remaining battery charge in percentage (%)
- the autonomy of the battery and therefore of the EV in hours (h).

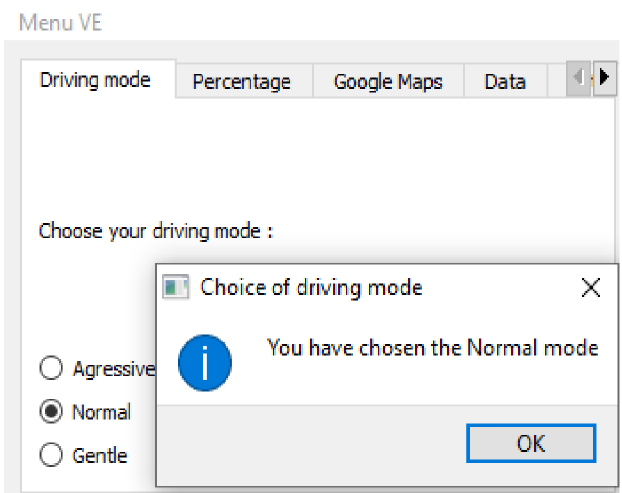
Moreover, all the data on the power spent for each stage (acceleration, normal driving, deceleration, ascent and slope) will be displayed, as well as the distances travelled at every segment.

A display of six tabs was therefore created in order to show all this information properly. The tabs designed are the following:

1st Tab: Driving mode

The user chooses their driving mode here, i.e., aggressive, normal or gentle (see Figure 2).

Figure 2 1st tab of the software program (see online version for colours)

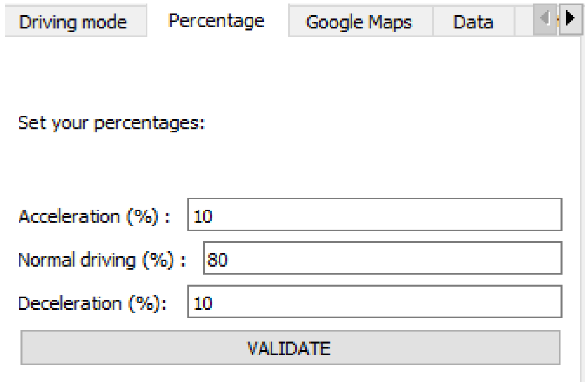


According to this mode, the acceleration taken into account in the calculations is different (Table 1). In order to validate his choice, it is necessary to select one of the 3 proposals. An informative message appears when the user has already selected one of the options.

2nd Tab: Percentage in horizontal path

In this second window, the user selects the percentages for acceleration, normal driving and deceleration on a horizontal path. Default values are already set up, but they can be changed at driver's choice (see Figure 3).

Figure 3 2nd tab of the software program

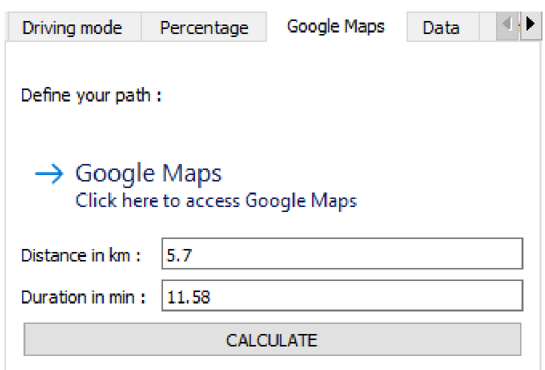


If the sum of the percentages is not 100%, a warning message appears, otherwise, an OK message shows up. It is necessary for the user to click on the VALIDATE button at the bottom of the tab to save the chosen values.

3rd Tab: Choice of the path

The user is directed to Google Maps through an informative page to enter his destination, from which distance and duration of the journey are provided. The user will then have to convert the values in kilometres and minutes on the software to make the calculations (see Figure 4).

Figure 4 3rd tab of the software program (see online version for colours)



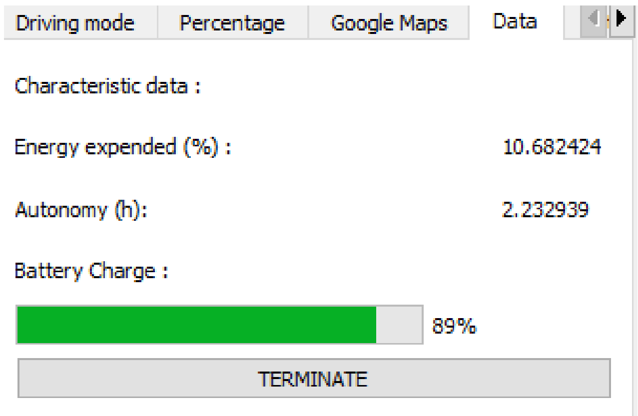
As soon as this is done, it is necessary to click on the CALCULATE button and an information message will appear to inform the user that the calculations have been done.

4th Tab: Display of characteristic data

The user should have access to the necessary characteristic values of the battery and the electric vehicle, i.e. (see Figure 5):

- percentage of energy dissipated (%)
- autonomy (h)
- remaining charge in the EV (%)

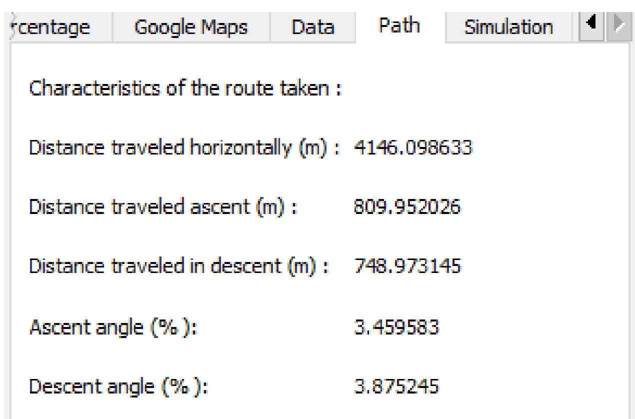
Figure 5 4th tab of the software program (see online version for colours)



5th Tab: Characteristics of the pathway

On this tab the user can check the characteristics of the path. These data are only for driver's information (see Figure 6).

Figure 6 5th tab of the software program



6th Tab: Simulation data

This tab provides useful information for the simulation with the setup explained in the next main part (see Figures 7 and 8).

Figure 7 6th tab of the software program

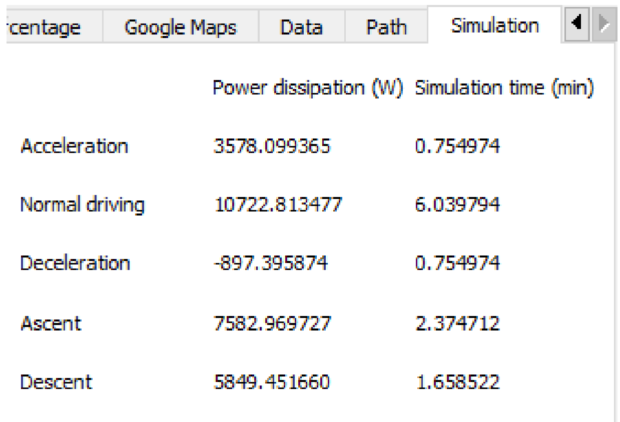
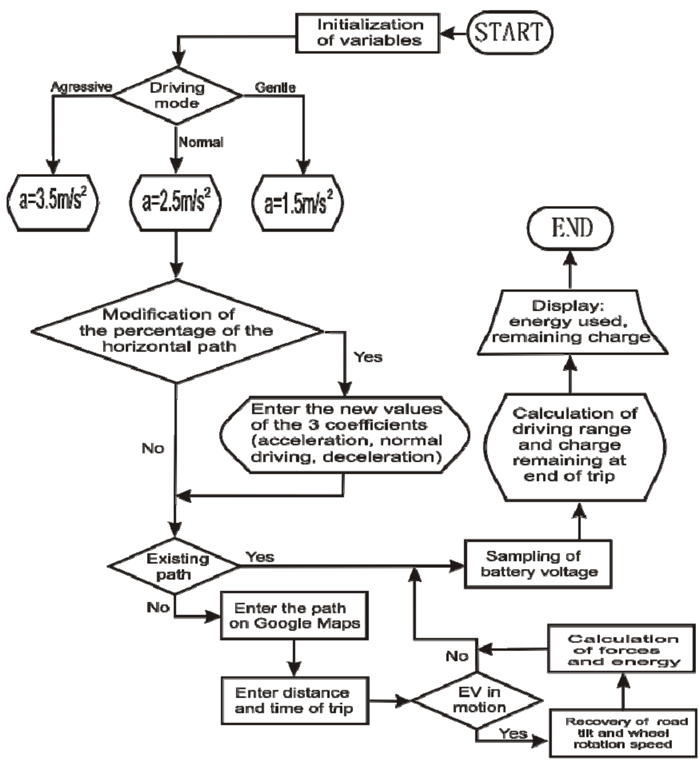


Figure 8 Software program flowchart



9 Conclusions

A new method to determine the electric vehicle range has been proposed. The method uses real driving conditions to improve the accuracy of the predictions. The protocol software is based on type of driving modes and on road characteristics.

Driving modes have been associated to an acceleration value, representing the most current habits of today's drivers, but other values can be implemented in the software. The protocol software is adaptive since most of the involved parameters can be updated at user's will.

The influence of the variation of battery capacity with discharge rate has been considered for the calculation of the available energy; since the driving conditions define the discharge rate, the calculation of the battery power and energy are adjusted to real situation.

The new method allows accurate predictions of electric vehicle range as well as the remaining charge in the battery at the end of a daily trip, thus warning the user the requirement of battery recharge based on next day trip energy use predictions.

The proposed methodology improves the existing methods since it takes into account real online values of parameters involved in the calculation, thus making the calculation of the electric vehicle driving range more accurate. It also can be applied to any driving conditions or driving mode, making the model more reliable.

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