# Speed profile optimization for electric vehicle with regenerative capacity

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## ABSTRACT

When we look at the existing driving assistances, we see plenty of them that aim at enhancing vehicle safety: longitudinal and / or lateral driving assistances that warn the driver or even take the control on the vehicle. Driving assistances can also help the driver to optimize the fuel consumption: they display an advice when the driver must change the gear position for instance. With the introduction of digital map and enhanced geometric contents, the driving assistances can even forecast a speed that optimizes the consumption on medium term (few seconds).

Furthermore, the electric vehicle presents a specificity as it can regenerate the electric energy while decelerating or maintaining a constant velocity on a downhill slope.

In the frame of the eFuture project (European FP7 project), we have developed methods that aim at providing a speed profile that take into account both safety and energy efficiency. The speed profile that we generate, can be used to supervise other longitudinal driving assistances, as ACC or FSRACC. In the following, we will describe several algorithms in order to improve the efficiency of electric vehicle with respect to these two objectives. The algorithms are of two families, each one has different assumptions and objectives which are explained. The last section is devoted to a comparison of solutions. However, we first explain the variables and models underlying our development.

We need to define the consumption, or the regeneration of electric energy. The engine torque computation could be evaluated as:

$$T_e = r(0.5\,\rho\,SCX\,V^2 + M\,g\,Crr + M\,a + M\,g\,\theta)$$

Where r is the wheel radius, ρ – the air volumetric mass , SCX – the air drag coefficient, V – the current vehicle speed, M – the vehicle's mass, Crr – the rolling resistance coefficient, a – the vehicle acceleration and θ – the slope of the road. Te is the torque that the vehicle need to generate in order to drive with a desired acceleration, through a given slope. Then, the engine speed w, assuming a non sliding tire, is:

$$w = v/r$$

Finally, we evaluate the kinetic energy and the electric energy that is either consumed or regenerated during a time dt, depending on the value of the torque:

| | consumption | Regeneration |
|---|---|---|
| Kinetic energy | $E_k = \frac{1}{\eta_g} T_e w\, dt$ | $E_k = \eta_g T_e w\, dt$ |
| Electric energy | $E_{elec} = \frac{1}{\eta_b} E_k\, \eta(T_e, w)$ | $E_{elec} = \eta_b E_k\, \eta(T_e, w)$ |

Where η_g is the transmission efficiency, η_b is the battery's efficiency and η the motor's efficiency. We must also describe the deceleration area where a regenerative braking is possible, depending on the vehicle speed. The deceleration domain could be approximated by a maximal deceleration γ_dec below a given value of the speed V_1. For speed that is higher, the deceleration is limited by the power of the motor:

$$\gamma_d(V) = \begin{cases} \gamma_{dec}, & V < V_1 \\ \frac{A}{V}, & V \geq V_1 \end{cases}$$

where A is a negative constant. Real characteristic of the motor can also be used.

After having developed the motor modelling, we described the methods to evaluate a safe and efficient computation using two approaches. The first one is not a real optimization as it computes a safe speed profile which limits the deceleration to a regenerative deceleration. The second one is a real optimization process using A* algorithm. We compare the results of the two methods in the last part of this article.

In this first method, we extend the principle of safe speed computation that is described in [1]: the deceleration is supposed to be constant on the whole speed range, which is no longer the case. The speed profile computation needs the knowledge of the legal speed limit, the road geometry and the limitation of acceleration in the curve.

In the second method, we directly use the safe speed limit from [1] without any consideration on the consumption in order to limit the exploration of the A* method. Then we optimize the speed, acceleration and deceleration, accordingly with the following cost function:

$$CF = C_1 Eelec_{norm} + C_2 t_{norm}$$

where $Eelec_{norm}$ - and tnorm are normalized values of the consumption and time. C_1and C_2 are the weighting factors. The heuristic for the A* algorithm is computed using the same function.

In order to demonstrate this simple approach, we have defined a simple road profile with two curves having radius of 100m and 200m, respectively, they are located at 200m and 400m. The road superelevation is correctly defined, given the sign of the curvature. The legal speed limit is 90km/h from 0 to 700m, and then drops at 70km/h. At 1000m, there is a stop sign, the legal speed is set to 0km/h.

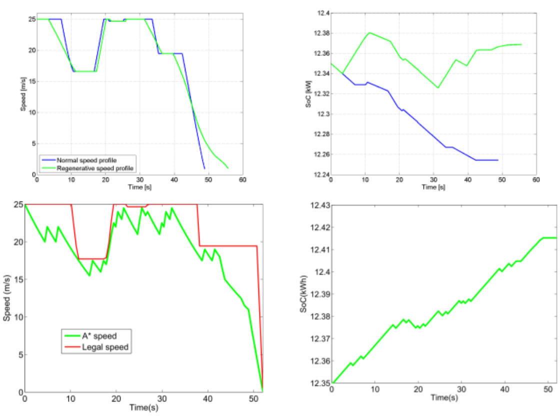


Figure 1 Speed profile and evolution of the state of charge for the two methods. In the second one the weights are set to optimize consumption over time

The results from the two methods are clearly positive. They show a real possibility to optimize the speed profile with safety and efficiency consideration (see Figure 1). The first method has the clear advantage of being a fast process with low memory usage. The second method has better results and can be tuned depending on the situation.

## CONCLUSION

In this article, we have demonstrated the feasibility of the optimization of a speed profile with respect to the vehicle specific capacity, both for consumption and regeneration. The first method shows to be fast and could be easily integrated on ECU to monitor the speed of functions such as ACC or ISA. The second method requires more computation, larger memory. These can be incompatible with embedded micro controller. However, it can be used for evaluation of consumption on a trip and speed advisory on a navigation device.

## BIBLIOGRAPHY

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