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Required power and energy demand determination of the vehicle in a movement for the particular route

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Abstract. This paper presents a method for power and energy demand estimation of a vehicle based on data obtained by a GPS device. During the selection process of the GPS device, it is necessary to take the sample rate and speed measurement accuracy into consideration. The power of an electric motor and energy of a battery pack need to be determined during the designing process intended for a conversion of a conventional vehicle to an electric vehicle. Drive requirements can be determined by measuring speed and torque on a drive wheel using a torque meter. Obtained traction profile is used for electrical drive designing purposes. The required power and the energy consumption of the vehicle can be calculated using speed and altitude profile from the measured route and the resistance model of the vehicle. The calculation for the Steyr 15S18 utility vehicle is proposed.

Key words

GPS device, energy demand, speed measurement, traction characteristic, utility vehicle

1. Introduction

An electric drive has different mechanical characteristics (torque vs. speed) in comparison with the traditional internal combustion engine. It is necessary to know a traction characteristic when sizing the electric drive for the purpose of converting a conventional car to an electric car. By using it, an appropriate electric drive (electric motor, inverter, and gearbox) and a battery pack can be selected. The traction characteristic can be determined by measuring angular speed and torque using a torque meter placed on a drive wheel [1], [2]. The method requires assembly and disassembly of a drive wheel. Therefore, it is complicated and requires expensive measurement equipment. Likewise, there is a possibility to gather data on – line through the CAN communication as it is presented in [3]. The method that uses CAN is only applicable to cars which have an appropriate software installed in their control units.
Most frequently, GPS utilization in the vehicles refers to route optimization for energy saving [4], calculation of wheel's parameters [5], and an estimation of the vehicle energy consumption [6]. Accelerometers and gyroscopes are sometimes used to determine terrain and vehicle parameters [7], [8]. This paper presents vehicle speed measurement using a GPS and an estimation of the traction characteristic using resistance coefficients. By using the proposed method, the electric drive system can be sized for an electric vehicle conversion. In addition, it is possible to design the drive system and adapt its requirements to the user regarding the specific route which is used. Utility vehicles, vans, and trucks are often used on the same route. Therefore, it is possible to optimize a drivetrain and a battery pack according to the route (range, maximum road gradient, and vehicle speed).

2. Vehicle resistances

In order to keep the speed constant or to accelerate a vehicle, a motor needs to overcome forces that are acting on road vehicles. Those forces are as follows:

- Rolling resistance force $\boldsymbol{F_{rr}}$
- Incline force $\boldsymbol{F_{gx}}$
- Acceleration force $\boldsymbol{F_a}$
- Air resistance force $\boldsymbol{F_w}$

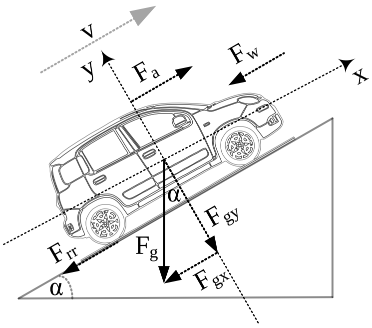

Figure 1 Decomposition of forces

The forces can be calculated using equations (1) to (4):

$$\boldsymbol{F_{rr}} = \boldsymbol{mgc_{rr}}\cos(\boldsymbol{\alpha}) \quad (1)$$

$$\boldsymbol{F_{gx}} = \boldsymbol{mg}\sin(\boldsymbol{\alpha}) \quad (2)$$

$$\boldsymbol{F_w} = \boldsymbol{c_d}\frac{1}{2}\boldsymbol{\rho A v^2} \quad (3)$$

$$\boldsymbol{F_a} = \boldsymbol{ma} \quad (4)$$

where m is the mass of a vehicle, g gravitational acceleration, c_{rr} rolling resistance coefficient, α slope angle, c_d aerodynamic drag coefficient, ρ air density, A front surface of the vehicle and v speed.
The amount of power lost with an average personal vehicle as a function of its speed is depicted in Figure 2.

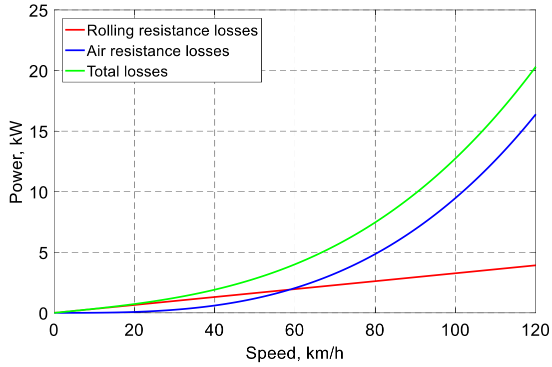

Figure 2 Overview of losses

The power used by the car is defined by the expression (5):

$$\boldsymbol{P}(\boldsymbol{v}) = (\boldsymbol{F_a} + \boldsymbol{F_{rr}} + \boldsymbol{F_{gx}} + \boldsymbol{F_w})\boldsymbol{v} \quad (5)$$

3. A GPS device

Commercially available GPS devices (mobile phones, GPS loggers, etc.) have a GPS module which receives data of the current vehicle location with the frequency of 1 Hz. From the distance set points, the GPS calculates speed as distance traveled over a time interval. The measured speed profile of the heavy utility vehicle STEYR is depicted in Figure 3. The GPS device has the ability to give altitude values based on geolocation. An altitude profile of the route is given in Figure 4.

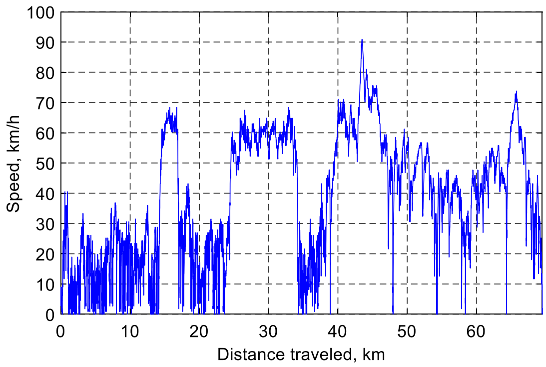

Figure 3 Speed of the heavy communal vehicle

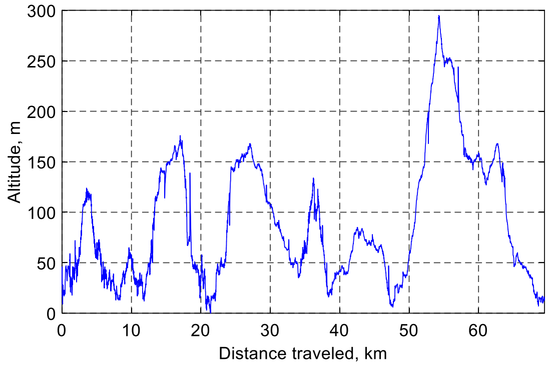

Figure 4 Traveled route altitude profile

As a result of relatively low sample rate and sharp signal changes, it is necessary to process data further in order to reduce the noise. In the further research, it is highly recommended to use a GPS device with the sample rate of 20 Hz. The 20 Hz GPS device uses Doppler effect to measure the speed of the vehicle [9]. That would make the vehicle speed measurement more accurate [10]. A comparison of measured data using both a 1 Hz and 20 Hz GPS (Figure 5) shows that the 20 Hz GPS device is more accurate in capturing vehicle dynamics.

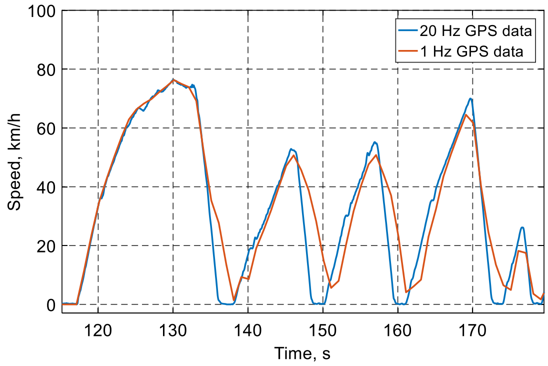

Figure 5 A comparison of speed measurements obtained with a different frequency

4. The calculation example of electric drive requirements for a heavy utility vehicle

The calculation of a power profile, speed, and traction characteristic is presented in this chapter. Vehicle speed and the altitude profile have been measured by the GPS device with the sample rate of 1 Hz. It is possible to obtain vehicle acceleration and the road gradient by using vehicle speed and the altitude profile. The speed signal (Figure 3) needs to be filtered and averaged. The GARMIN OREGON 450 GPS device has been used. The GPS device receives data with a frequency of 1 Hz.

Technical specifications of the heavy utility vehicle Steyr 15S18 are given in Table I.

Table I Technical specifications of the vehicle

Mass [kg]	**11000**
Width [m]	**2.4**
Height [m]	**3.2**
Rolling resistance coefficient	**0.008**
Aerodynamic drag coefficient	**0.9**
Vehicle tyre diameter [m]	**1.07442**

By replacing resistance coefficients in the vehicle model with values from Table I, required power can be calculated using vehicle speed as an input for expression (5). As a result of unavailable official data from the manufacturer, air and rolling resistance coefficients are obtained from the known experimental values. It can be seen in Figure 6 that the peak power (approximately 125 kW) of the vehicle is measured at the 50 km mark. The peak power is a result of a relatively high slope (maximum slope of 7%) and high speed (50 km/h). Compared to the required power for traveling 60 km/h on a flat road surface, which is approximately 33 kW (given in Table II), it is significantly larger.

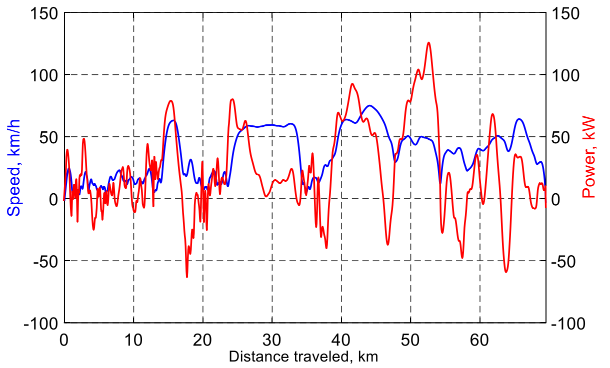

Figure 6 Calculated required power of the vehicle for the traveled route

Likewise, by using analytical calculations, drive characteristics are determined considering maximum speed requirement and slope of the ramp (Table II and Table III). At the calculation, assumed acceleration was 0.278 m/s^2 what corresponds to speed increase from 0 to 5 km/h in 5 s.

Table II Analytical calculation of drive characteristics considering maximum speed requirement

Maximum speed [km/h]	**60**
Slope [%]	**0**
Air resistance force [N]	**1152**
Rolling resistance force [N]	**863**
Gravitational force in x-direction [N]	**0**
Acceleration force [N]	**0**
Torque on the wheel [Nm]	**1082**
Angular speed of the wheel [rad/s]	**31.02**
Power [kW]	**33.56**

Table III Analytical calculation of drive characteristics considering slope of the ramp

Maximum speed [km/h]	**5**
Slope [%]	**17**
Air resistance force [N]	**8**
Rolling resistance force [N]	**851**
Gravitational force in x-direction [N]	**18085**
Acceleration force [N]	**3056**
Torque on the wheel [Nm]	**11819**
Angular speed of the wheel [rad/s]	**2.59**
Power [kW]	**30.61**

The maximum vehicle load represents climbing to the landfill when the vehicle needs to overcome an ascent with an average road gradient of 6% and average speed of 50 km/h. The total efficiency of the system η_s = 65% was assumed. Calculated energy demand for the travel route, as well as the altitude profile, are shown in Figure 7. As a backup, the total energy in the battery pack is increased by 20% and equals to 104 kWh. An auxiliary energy of 18 kWh is added as an approximation of the vehicle auxiliary onboard systems (6 kW times 3 hours of constant operation). The slope of the energy curve is positive when the vehicle is draining energy from the battery pack, and negative when the regenerative braking is feeding energy to the battery pack. The route is depicted in Figure 8.

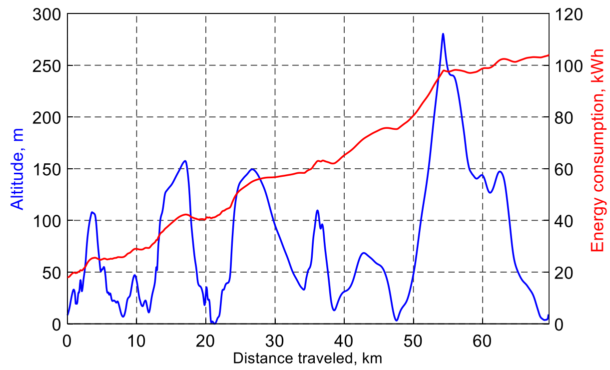

Figure 7 Calculated energy demand of the vehicle for the traveled route

Calculated data offer an opportunity to size the electric drive further, respectively choose an electric motor, inverter, gearbox and battery pack for the vehicle.

It is necessary to have more accurate data about the vehicle resistance coefficients in order to get more accurate power calculation. Moreover, assumed aerodynamic drag, as well as rolling resistance, should be directly measured. According to that, further research and effort to identify vehicle resistances are being suggested.

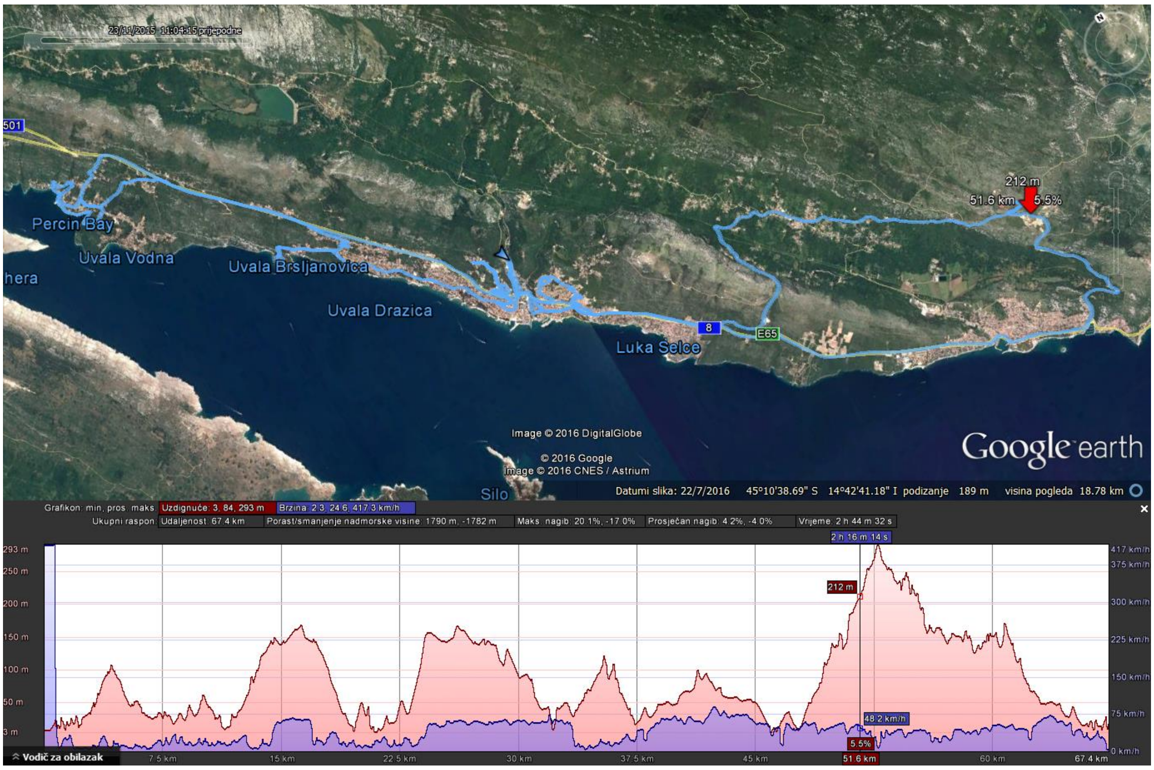

Figure 8 Overview of the route on the map

5. Conclusion

The proposed estimation method of the vehicle's traction characteristic by using GPS device allows power and energy estimation for the particular route. The method can be applied to all road vehicles. It does not require additional mechanical adaptation of the vehicle. Measurement can be performed by mounting a GPS device. To improve the method, a GPS device with a better sample rate and measurement of the road gradient using a gyroscope as well as vehicle acceleration measurement using an accelerometer should be used. Power and torque calculation can be used to size an electric drivetrain and it represents a plan for the further research. Moreover, in the future work, measuring system should be developed.

References

[1] Ban, Branko; Vražić, Mario; Bahun, Ivan. “Electric Vehicle Model with Driving Cycle based Algorithm for Battery and Motor Minimization,” *Proceedings of the 18th International Conference on Electrical Drives and Power Electronics*, EDPE 2015., 2015., pp. 220-226.

[2] A. Niedworok, „Dynamic torque measurement of drive transmission in vehicles being in motion using strain gauges measurement technique and wireless data transmission,“ *Power Electronics and Applications (EPE'14-ECCE Europe)*, 2014 16th European Conference on, Lappeenranta, 2014, pp. 1-8.

[3] A. Alessandrini, F. Filippi, F. Ortenzi, „Consumption calculation of vehicles using OBD data,“ *20th International Emission Inventory Conference*, Florida, USA, 2012.

[4] N. Jovičić, *et. al.*, “Route optimization to increase energy efficiency and reduce fuel consumption of communal vehicles,” *Thermal Science*, Volume 14, 2011, pp. S67–S78.

[5] R. Anderson and D. M. Bevly, „Estimation of tire cornering stiffness using GPS to improve model based estimation of vehicle states,” *IEEE Intell. Veh. Symp. Proc.*, 2005, pp. 801–806.

[6] A. D. Ourabah, B. Quost, A. Gayed and T. Denœux, *"Estimating energy consumption of a PHEV using vehicle and on-board navigation data,"* 2015 IEEE Intelligent Vehicles Symposium (IV), *Seoul, 2015, pp. 755-760.*

[7] J. Ryu and J. C. Gerdes, "Estimation of vehicle roll and road bank angle," *Proceedings of the 2004 American Control Conference*, Boston, MA, USA, 2004, pp. 2110-2115 vol.3

[8] R. Wragge-Morley, G. Herrmann, P. Barber and S. Burgess, "Information fusion for vehicular systems parameter estimation using an extended regressor in a finite time estimation algorithm," *2014 UKACC International Conference on Control (CONTROL)*, Loughborough, 2014, pp. 401-406

[9] T. J. Chalko, “High accuracy speed measurement using GPS (Global Positioning System),” *East*, 2007, pp. 1–9.

[10] A. Salih, N. Zaini, A. Zhahiri, “The Suitability of GPS Receivers Update Rates for Navigation Applications”, *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering* Vol:7, No:6, 2013, pp 1012-1019.