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THE PROPOSAL OF THE CALCULATION ALGORITHM PREDICTING THE REAL VEHICLE FUEL CONSUMPTION

In the present times energy saving is one of the most challenging tasks, faced by the modern society. The automotive industry experiences it to a very high extent, not only because of the obvious facts about consuming fossil fuels (which are limited), but also because it attracts common attention of the society itself. The automotive industry is being forced by the authorities to limit the fuel consumption of the produced vehicles by means of new legislation (RDE measurements, WLTP, progressing limitation of the internal combustion engines for driving vehicles, etc.). Although the knowledge about the fuel and energy consumption is very rich, there are still aren't many representative procedures to predict the fuel consumption of a vehicle. The paper tries to collect the knowledge of the physical laws applied to describe vehicle motion, present commonly available technology (GPS) and simulation calculation methods to develop a tool to accurately predict the real vehicle fuel consumption.

Keywords: fuel consumption, vehicles, measurements, simulation

1. INTRODUCTION

A vehicle is a mean of transportation designed to move on a road or a machine or device adapted for this purpose [Ustawa, 1997]. The transportation of people and goods was important throughout all the history of humanity. The optimization of transport methods continues, from the first use of an animal to move from one point to another, until today. The most common method of transport nowadays is to use a wheel vehicle propelled by an internal combustion engine, powered by one of the conventional fuels [Chan et al. 2016].

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The combustion of the fuel to propel the vehicle is controversial from both perspectives: reduction of the limited natural resources and production of air pollutants [Merkisz, Pielecha, Radzimirski 2014; Merkisz, Pielecha 2015]. The reduction of the necessary propelling energy [Merkisz, Pielecha 2015; Cieślik, Pielecha, Borowski 2015], thus fuel, is desired by the natural environment, society, authorities and the industry. Below is a compiled list of factors influencing the vehicle energy consumption.

Table 1

Factors influencing vehicle energy consumption [Chen et al. 2016]

Constructional factors	Environmental factors
vehicle mass and inertia of rotating parts, vehicle shape (and shape changing systems), construction of tires, powertrain efficiency, resistance of rotational parts (bearings, brakes, etc.).	atmospheric conditions (air temperature, density, viscosity), wind direction and speed, terrain shape, road surface state and art.

The factors listed in Tab. 1 do not concern the process of providing the energy (power source and power modifiers), nor do they concern the way of achieving vehicle motion (driving style, calibration of the power control devices). They are purely focused on vehicle energy consumption.

The methods of determining vehicle energy consumption, in relation to fuel consumption, were described in author's thesis [Sidorowicz 2014]. An interesting method is used in European vehicle homologation procedure [Merkisz, Pielecha, Radzimirski 2014]. Currently the procedure consists of measurement of road load (with coast down or hub torque method) and performing the laboratory test using a chassis dyno with exhaust gas analyzing system. Based on the average CO_2/km value the fuel consumption value is calculated, which is a base for a conclusion about vehicle energy consumption. The new regulations introduce the RDE (Real Driving Emissions) measurement – i.e. on the road, instead of in the laboratory [Merkisz, Pielecha, Radzimirski 2014]. However, this method is still not going to cover all of the factors influencing vehicle energy consumption, especially the environmental ones.

The difficulty to exactly determine the on-road vehicle energy consumption without the physical prototype or the vehicle itself is caused by not considering all the factors listed in Tab. 1. This paper is an attempt to elaborate the analytical-simulation tool to determine the real on-road vehicle energy consumption.

2. MEASUREMENT, CALCULATION AND SIMULATION METHODOLOGY

The execution of the described algorithm is performed by calculating instantaneous (in every time step) energy consumption by summing up the partial consumers' share. The algorithm's block diagram is shown in Fig. 1.

As can be concluded, the key to a correct calculation is the data. This is the reason that the statutory procedures of homologation of the vehicle fuel consumption make many assumptions (often wrong or too simple), e.g. the driving cycle not including the slope of the terrain.

Regarding the vehicle data, much of it is available only to the vehicle or subsystem manufacturer. To exactly predict the vehicle energy consumption when the data is not provided, many measurements, usually complicated and expensive, need to be conducted.

The information of the terrain topography can be nowadays obtained relatively easily. Global Positioning System (GPS) is commonly available for almost every mobile phone owner. Free software, which is also available to be downloaded and used, in combination with the GPS sensor built in the mobile phone allows to record the position on the Earth, including height.

Driving behaviour is a form of boundary conditions. It is more realistic to simulate driving behaviour in the way of limits on maximum acceleration, deceleration and speed in combination with terrain data rather than giving single speed profile to a route, which is far more abstract.

Calculating the forces acting on the vehicle can be performed by using commonly known and described [Siłka 1997] formulas.

3. ALGORITHM FEATURES

The described algorithm to calculate energy consumption of a vehicle in motion has the advantages of simplicity and modularity. This makes it easy to implement and leaves the opportunity to expand the calculations by new technologies influencing the energy consumption (stop/start system, multiple engine maps, hybridization, braking energy recuperation, etc.) [Merkisz, Pielecha 2015]. In author's thesis [Sidorowicz 2014] the attempt was made to implement this algorithm for special use (Formula Student car) in Matlab-Simulink environment.

The algorithm combines physical measured data with analytical calculations. This creates a significant result uncertainty. To improve the algorithm results accuracy, the vehicle model needs to be correlated with the physical object by using the other energy consumption method (e.g. turbine fuel flow meter [Sidorowicz 2014]).

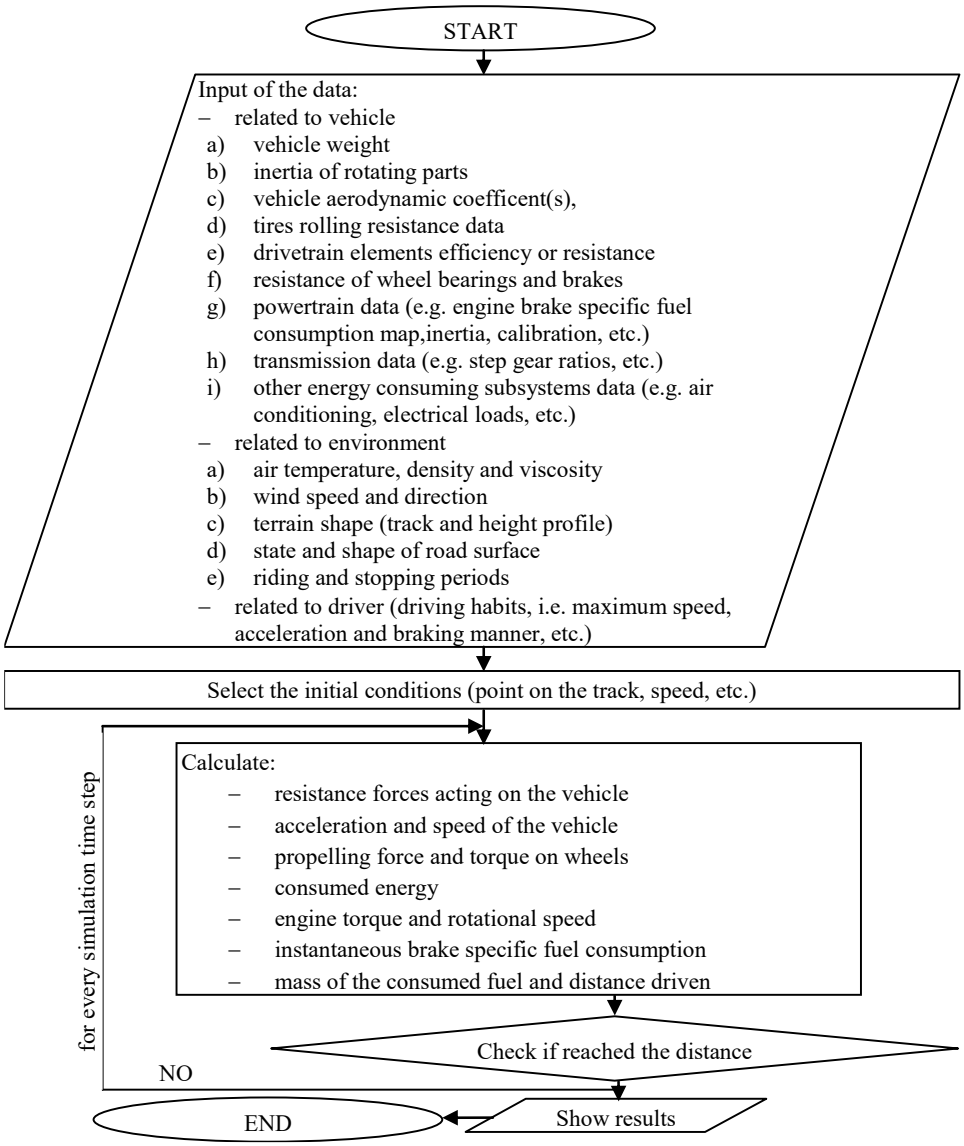

Fig. 1. Block diagram of the described algorithm to calculate vehicle fuel consumption

The correlation can be applied to single vehicle systems, when the data is not available. For example, the calibration of modern powertrain control unit is rarely available for customers. The correlation of the temperature influence on the break specific fuel consumption map must be realistic, although it is difficult to measure.

The disadvantage of the algorithm is its assumption of using every possible data influencing energy consumption, which makes it difficult to use in automotive industry. However, the current trend shows the drop in building vehicle prototypes [Kulkarni et al 2011] and more use of Computer Aided Design (CAD) data.

An example usage of the algorithm is presented below. The Formula Student car starting in Formula Student Czech Republic competition in 2014 was subjected to the research of the tank size design [Sidorowicz 2014]. The track was recorded using a GPS module in a mobile phone and transferred to the Matlab-Simulink software (Fig. 2).

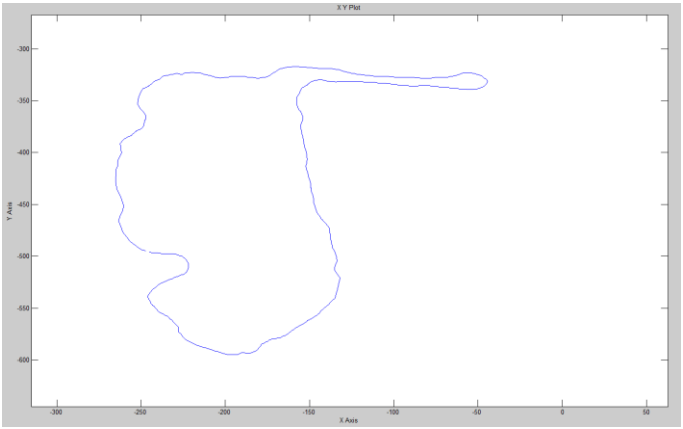

Fig. 2. The track geometry used to calculate fuel consumption

In spite of many simplifications made in provided data due to its inavailability, the algorithm was able to provide reasonable result of average fuel consumption of 14.47 dm3/100 km (Fig. 3). Verification of the result was not performed though.

4. CONCLUSIONS AND SUMMARY

This paper describes the implementation proposal of the algorithm to simulate vehicle motion to find information about vehicle energy consumption. Energy saving is one of the main directions of automotive industry development. Using the proposed algorithm could help optimize the vehicle energy consumption in the most efficient way.

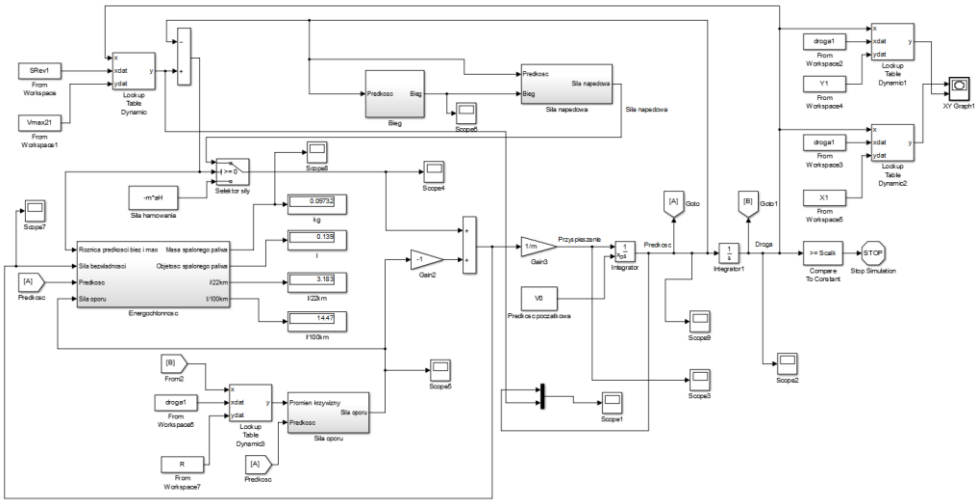

Fig. 3. Matlab-Simulink based algorithm with calculated result of average fuel consumption

The algorithm is intended to be as universal as possible. It is characterised by its modular character, allowing change of the systems and technologies applied in the vehicle, e.g. changing the classic powertrain to a hybrid one with adjustable calibration for further optimization.

The described algorithm is based on the implemented known vehicle drive technologies. Assuming the future development of powering the vehicles it can be used to preliminarily test the developed technologies assuming other parameters as constant. Such usage might provide the real answer about the energy saving before moving on to physical tests.

The calculations of the vehicle dynamics are performed using the provided data and scientifically described physical laws. This approach results in a very robust method of predicting vehicle energy consumption, with opportunity of further improvement (correlation).

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PROPOZYCJA ALGORYTMU OBLICZENIOWEGO PRZEWIDUJĄCEGO RZECZYWISTE ZUŻYCIE PALIWA POJAZDU

Streszczenie

Obecnie oszczędzanie energii jest jednym z największych wyzwań, które stawiane jest nowoczesnemu społeczeństwu. Przemysł motoryzacyjny doświadcza go w wielkim stopniu, nie tylko z powodu oczywistego faktu zużywania paliw kopalnych (których ilości są ograniczone), ale również dlatego, że przyciąga to ogólną uwagę samego społeczeństwa. Przemysł motoryzacyjny jest zmuszany do ograniczania zużycia paliwa z produkowanych pojazdów przez nowe przepisy legislacyjne (pomiary drogowe, postępujące ograniczanie silników spalinowych do napędu pojazdów, itd.). Mimo tego, że wiedza na temat zużycia paliwa i energii jest bardzo bogata, nadal nie ma wielu reprezentatywnych procedur do przewidywania zużycia paliwa przez pojazd. W artykule podjęto próbę opisu ruchu pojazdu z wykorzystaniem dostępnej powszechnie technologii GPS oraz obliczeniowych metod symulacyjnych w celu opracowania narzędzia do poprawnego przewidywania rzeczywistego zużycia paliwa przez pojazd.

Słowa kluczowe: zużycie paliwa, pojazdy, pomiary, symulacja