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Data Acquisition Unit for Generation of Realistic Driving Cycles from Real World Data

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Abstract

Standardized driving cycles like the NEDC do not reflect a realistic behaviour of drivers and are therefore not ideal to test the fuel consumption of cars. This article describes an easy to use method to generate realistic driving cycles using data from a GPS sensor, from the car's ECUs and the on-board electrical system. So realistic urban, suburban and motorway-driving cycles can be measured taking into account the demands of different drivers. A method for the reconstruction of the gear-information from the data of the engine control unit is shown. The altitude profile measured with the GPS sensor is compared with SRTM-data (Shuttle Radar Topography Mission) and DTED-data (Digital Terrain Elevation Data), mostly shipped with standard navigation software. The complete system is demonstrated by means of an exemplary measurement of an inner city driving cycle.

simulation, city traffic

1 Introduction

Since 1996 in the European Union, the fuel consumption of cars is measured with the standardized driving cycle NEDC (New European Driving Cycle). For that, the cars are driven on an roller dynamometer. In other countries the same procedure is used with different driving cycles. The fuel consumption of a vehicle depends on 5 major forces: The acceleration, the wind load, the rolling friction of the tires, the slope and the load of the auxiliary equipment like generator, power steering and air conditioning compressor. Neglecting one of the forces automatically results in a lower fuel consumption. In almost all test cycles at least one of the forces is neglected [2]. The NEDC used in the EU and the 10-15Mode used in Japan for example, are synthetic driving cycles with precisely defined conditions in opposed to the FTP75 (Federal Test Procedure) used since 1975 in the USA which is a real world driving cycle. The standardized driving cycles with prescribed gear shifts represent only average values of the behaviour of different drivers [1]. They do not consider different types of drivers, like sportive drivers or economic drivers, nor do they consider the altitude profile of the track and the load of the on-board electrical components. The high number of electrical additional components like seat heater, electrical exterior mirror and the climate control generate additional fuel consumption which cannot be neglected. The synthetic driving cycles also exhibit too little variation in the speed profile in comparison with real world driving cycles [2] which reduces the loss caused by the acceleration forces. Almost all cycles used to calculate the fuel consumption have a top speed of only $120\,km/h$ ($\approx 74\,mph$) so that cars with a high drag coefficient like SUV's are favored because of their fast rising fuel consumption at increasing speed. Also the accelerations are very low in all synthetic driving cycles. A typical acceleration is from standstill up to $50\,km/h$ ($\approx\ 31\,mph$) in as many as 26 seconds in the NEDC for example. Standardized driving cycles therefore are hardly representative of normal driving conditions. So the fuel consumptions indicated in the advertising material and technical data sheets of car manufactures are too low and cannot be achieved by normal drivers in real world conditions.

For realistic fuel consumptions cars should be ideally tested with real world driving cycles to cover several different kinds of driving [1]. Even the average driving may differ between regions. We use real world driving cycle data with the hybrid drivetrain simulation tool "FAHRSIM" [6] to gather more precise information of the fuel consumption of conventional and hybrid cars [5]. The necessary data for the driving cycle data is collected with a data acquisition unit which is presented in the further article.

2 Data acquisition

2.1 System overview

In Figure 1 the complete data acquisition system is shown [4]. Core of the system is a data acquisition unit with a multi-bus-interface. This Plug-and-Play facility simplifies the measurement of all sorts of relevant driving cycle informations. Available are one RS232 interface for a GPS-Sensor, one K-Line interface for the connection with an engine controller unit, two RS485 interfaces for up to 64 sensors and an optical and electrical CAN-Interface. The logged data is written on a standard SD storage card with up to $2\,GB$ of memory using the FAT32 file system. The data is written as a colon-separated "CSV-File" which can easily be used with almost every analysis software like MATLAB or EXCEL.

The sampling time of the data acquisition unit is $100\,ms$. This is adequate to reconstruct all necessary information concerning the driving because there are no transients requiring shorter sampling times. Only the load of the on-board electrical components may have faster transients than $100\,ms$. This does not mean a no limitation because the loss of the transients in the electrical load-profile does not change the mean value of the load significantly. A faster sampling would also lead to an exploding data amount. At a sampling time of $100\,ms$ the memory demand is about $100\,kByte$ per minute collecting only the necessary data for the reconstruction of the driving cycle.

2.2 Sensor modules

2.2.1 OBD II interface

The data acquisition unit uses the data provided by the OBD II diagnostic interface. The OBD-II standard specifies the type of diagnostic connector and its pinout, the electrical signalling protocols available, and the messaging format. All gasoline cars sold in the EU since 2001 and all diesel cars since 2004 are equipped with this standardized diagnostic connector. Important vehicle parameters can be monitored over this interface for example, the actual speed and actual engine speed. With the two implemented protocols ISO 9141 and ISO 14230 all cars of the VAG group (VW, Audi, Skoda,SEAT group) can be easily accessed. So the data acquisition unit is not limited to one test vehicle. With this interface the actual speed, the engine speed and torque, the position of the throttle and the amount of fuel injected are measured.

2.2.2 GPS interface

With the GPS sensor, the actual position, the actual speed over ground and the actual altitude are measured. The GPS sensor is also used to synchronize the time to get precise time stamps. With the implemented NMEA-protocol (National Marine Electronics Association) almost every sensor can be used. The data is transmitted via the RS232-bus as an ASCII-string to the data logging unit.

2.2.3 Sensor-bus

With the sensor-bus up to 64 sensors can be connected to the data acquisition unit. The address allocation is totally automatic, so that it is easy to reconfigure the complete system. There are several modules to measure the temperature, voltage or current. The use of one unique bus sys-

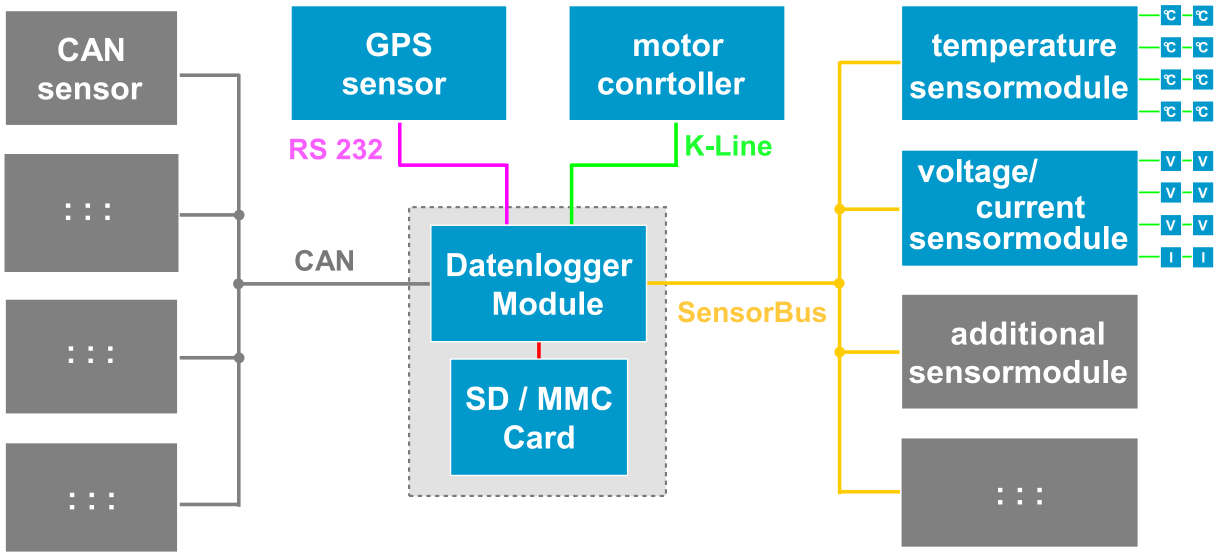

Figure 1: Overview of the data acquisition unit

tem reduces the complexity of wiring. A sensorbus module consists of two parts. One part is only responsible for the communication with the data logging unit while the other part is used for the preprocessing of the different sensor signals. This makes it easy to construct new sensor modules because only the low-level hardware has to be changed. Currently the following sensor modules are available:

Temperature sensor module	8 Pt1000 temperature probes range: $-38^oC \cdots 162^oC$, resolution: $0,2^oC$
Voltage sensor module	4 software-configurable voltage inputs range: $0V \cdots 10V, 0V \cdots 20V$, $-10V \ldots + 10V, -20V \cdots + 20V$ resolution: $0,61mV$, $1,22mV$, $1,22mV$, $2,44mV$, respectively
Current sensor module module	range: $0A \cdots 200A$, $0A \cdots 400A$, $-200A \cdots 200A$,$-400A \cdots 400A$ resolution: $12,2mA$, $24,4mA$, $24,4mA$, $48,8mA$, respectively

Table 1: Available sensor modules

Figure 2: A aerial photo of an inner city driving cycle

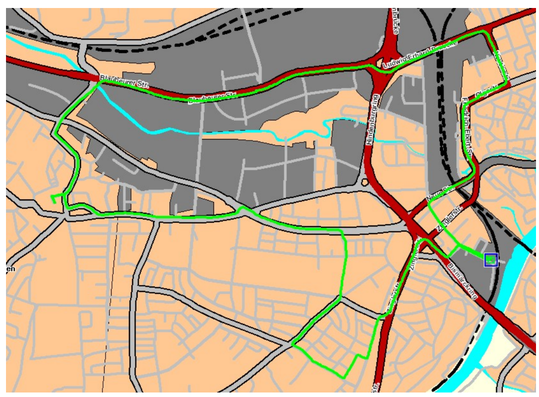

Figure 3: Map of an inner city driving cycle

3 Measurement of a UCC (Ulm city cycle)

Figure 2 shows the aerial photo of an exemplary driving cycle UCC (Ulm City Cycle).The driving cycle is a typical German inner city cycle with a maximum driving speed of $64\,km/h$ ($\approx 37\,mph$). The driving cycle consist of two parts with almost the same length. One part on side roads (grey roads in the map in figure 3) in a residential district with speed limits of $30\,km/h$ ($\approx 19\,mph$) and $50\,km/h$ ($\approx 31\,mph$) and a second part, a ride through an industrial area on main roads with speed limits of $50\,km/h$ and $60\,km/h$ ($\approx 37\,mph$) (red roads in the map in figure 3). This driving cycle can be compared with the first parts of the NEDC, which also should represent an inner city driving cycle.

3.1 Extraction of the speed information

3.2 Extraction of the gear information

The measured engine speed and the vehicle speed can be used to extract the gear information. Therefore, the actual speed is divided by the engine speed of the car which results in a transmission ratio. The calculated transmission ratio of a part of the UCC is shown in figure 4. If the clutch is closed, the result of the calculation can be easily assigned to one of the five gears because of a fixed transmission ratio. If the clutch is opened there is no fixed transmission ratio between the engine speed an the speed of the car and the calculated value is undetermined. This normally only occurs in the short moment of changing a gear. There is a big difference between upshifting and downshifting. If the driver is shifting up, the engine speed decreases very quickly whereas the speed of the car remains almost constant in the moment of shifting. Therefore the calculated transmission ratio rises which indicates a higher gear. If the driver is shifting down, the engine speed also decrease, because of the opened clutch, before it rises very fast after closing the clutch, whereas the speed of the car is almost constant in the moment of shifting. This too, produces a high transmission ratio for the moment of shifting which can be wrongly interpreted as a higher gear. The calculation is embedded in a "'MATLAB"' driving cycle generation tool. In this function the typical behavior of a human is implemented to avoid errors produced by the different behaviour of upshifting and downshifting. For plausibility, the gear vector is tested on a continuous sequence. Also the -length of time a gear is used is monitored to suppress unnaturally fast shifting. There is no need of a manual correction of the gear vector afterwards.

3.3 Extraction of the altitude profile

The altitude profile and the speed profile of the car are used to calculate the actual slope. The slope force has a strong influence on the fuel consumption especially for heavy cars and cannot be neglected. The slope is calculated with the following formula:

$$tan\,\alpha = \frac{\frac{d}{dt}speed}{\frac{d}{dt}speed} \qquad (1)$$

The accuracy of the altitude measured with a GPS-Sensor depends directly on the number of satellites connected. Of course, visibility is necessary for a connection to a satellite. Therefore, in the inner city a possible loss of connections is most likely because of the buildings, resulting in reduced accuracy in the altitude measurement: steps of up to $40\,m$ within seconds are possible. Especially at low driving speeds, these variations of the altitude cause errors in the slope calculation. Therefore the data of the SRTM altitudes [3] is used to calculate the slope because of their higher precision.

3.3.1 Comparison of the altitude profile

In figure 5, the altitude measured with a GPS sensor, the SRTM- and DTED-data is compared for the UCC and a suburban driving cycle. For a suburban driving cycle the altitude measured with the GPS sensor corresponds very well to the altitude, extracted from the SRTM-data as there is no blocking by tall buildings. In the UCC there are several spikes with a high aberration between the SRTM-data and the GPS-data which is due to the loss of satellite connection in the inner city. Only few parts of the altitude profile do agree with the SRTM-data, so that the GPS altitude profile is useless. The DTED-data can not be used due to the lower resolution of the data. The resolution of the different data is listed in table 2.

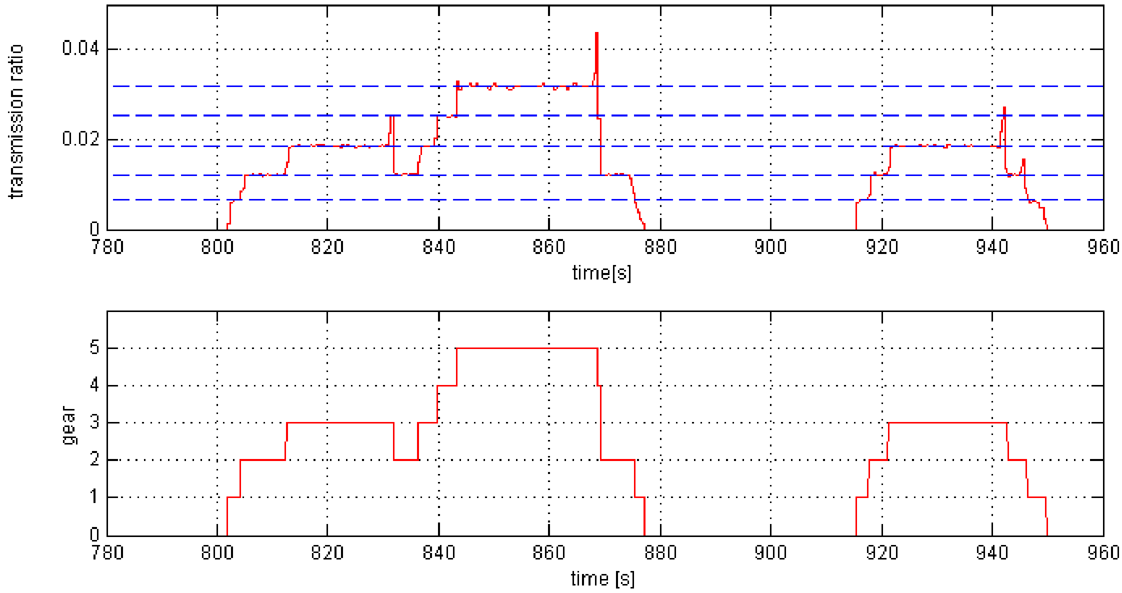

Figure 4: Top: transmission ratio - Bottom: extracted gear information

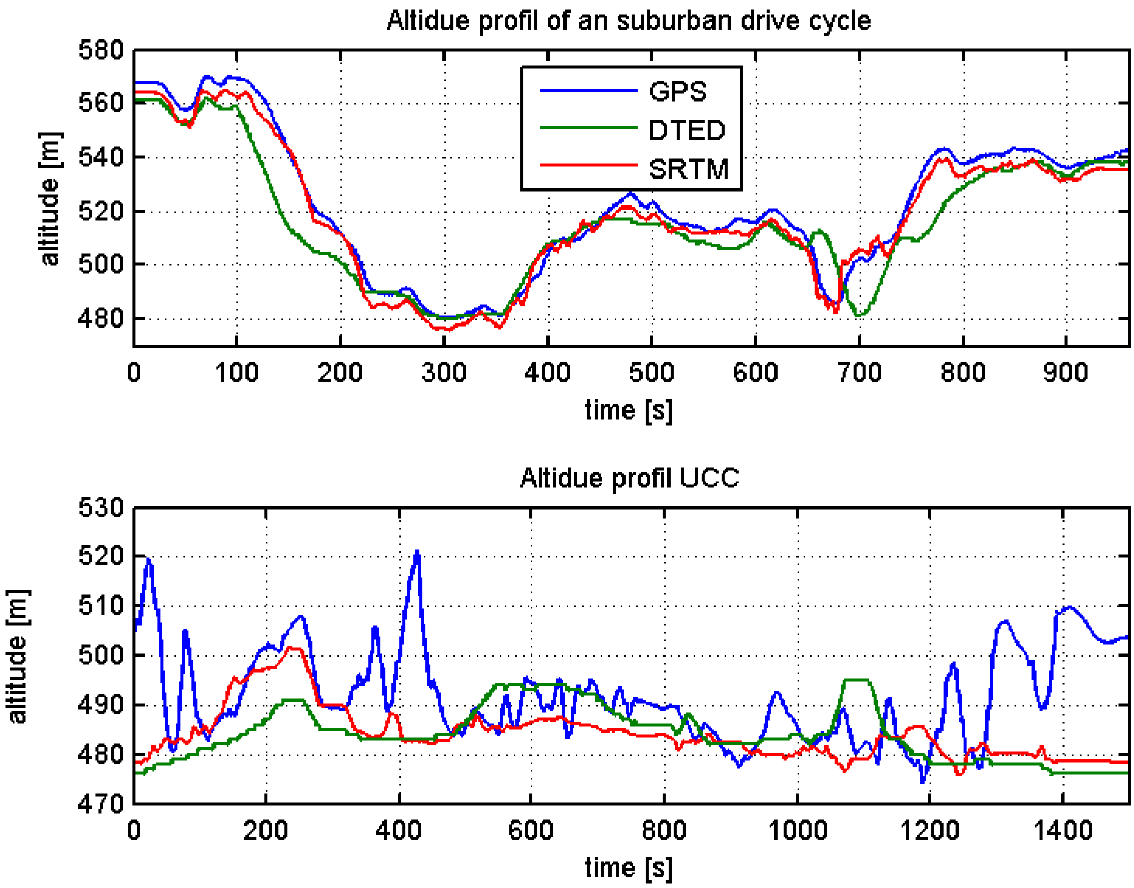

Figure 5: Comparison between GPS, SRTM and DTED data

GPS-Sensor [4]	vertical resolution: $0.1m$ accuracy: $\pm 3 - 5\,m$ (DGPS)
SRTM 3 Data [3]	resolution: 3 arcsecond altitudinal belt: 1m horizontal accuracy: $\pm 20m$ @ 90% accuracy vertical accuracy: $\pm 16m$ @ 90% accuracy
DTED-0 Data	resolution: 30 arcsecond

Table 2: Resolutions of GPS, SRTM and DTED data

3.4 Extraction of electrical on-board net information

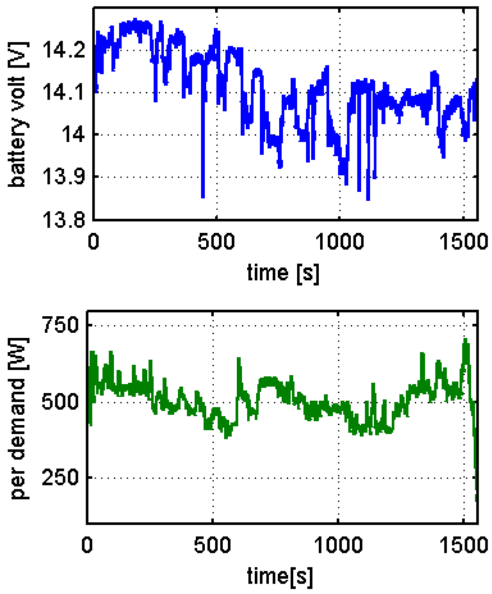

Figure 6: Electrical on-board net information

The power demand of the electrical on-board components can be calculated with the measured generator output current and the actual voltage of the battery. This power demand results in an additional engine torque which cannot be neglected because of the poor efficiency of the generator. In the UCC an average power demand of $500\,W$ was measured for the test car used. This would cause an additional engine torque of about $5.3\,Nm$ at an engine speed of $1500\frac{1}{min}$ and a maximum generator efficiency of 60%. Figure 6 shows the dynamic power demand of the electrical on-board components during the UCC.

4 Influence of the driver on the fuel consumption

With this data acquisition unit a lot of real word driving cycles can easily be measured and analysed. The analysis of the driver's influence on the fuel consumption is only one example of the possibilities of the data acquisition unit. Figure 7 shows the speed profile of test route driven by different drivers. The speed profiles plotted over the total driving distance show only little variation between the three drivers. The speed profile mainly depends on the test route. A big variation, however, is shown in the gear vector of the different drivers in figure 8. Driver 2 is very a economic driver who uses the highest possible gear. This results in a much lower fuel consumption as compared to the other drivers. Driver 1 and driver 3 are using much lower gears which results in a higher fuel consumption. The fuel consumption for the test route varies within a range of 10% between the drivers.

5 Conclusion

The data acquisition unit is an easy to use method to measure different types of real world driving cycles. The accuracy of the real world data benefits from the using SRTM data to generate the altitude profile. It is also possible to measure the load of the on-board electrical components which were neglected in the most driving cycles. These real world driving cycles allow to gather more realistic and precise information of the fuel consumption of conventional and hybrid cars with our (or any other) hybrid drivetrain simulation tool "'FAHRSIM"' .

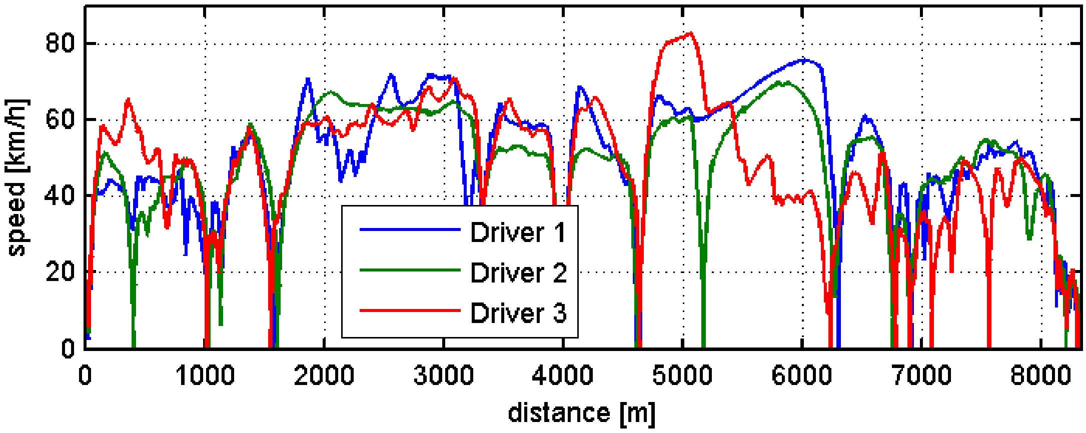

Figure 7: Speed profile

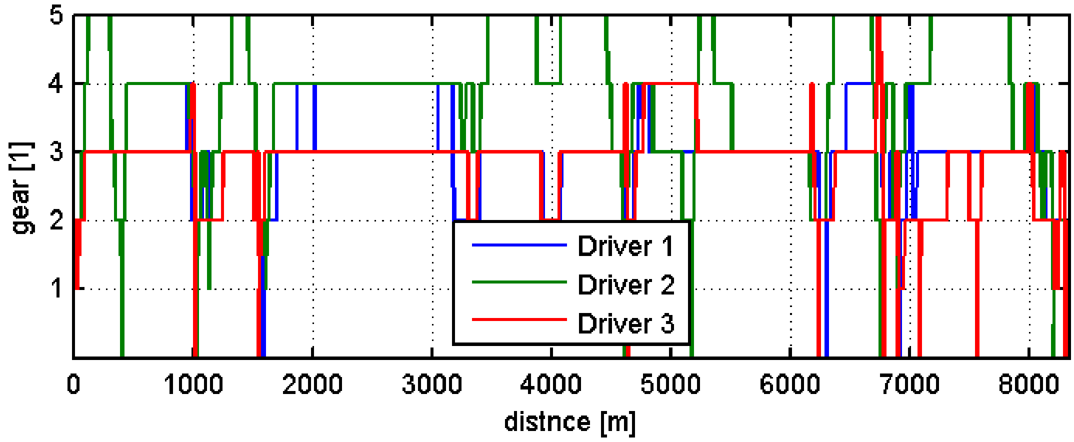

Figure 8: Gear vector

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