GPS based data acquisition system for mobile applications

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Abstract: The Global Navigation Satellite Systems allow an accurate determination of the position in a geocentric reference system, using the signals from the artificial satellites network, received with dedicated devices. The GPS devices are well known and used by many people, especially for navigation. These are commercial GPS devices, which can be found at decent prices. Professional devices also exist for geodesic applications, and even for dynamic data acquisition. These are much more precise devices, but more expensive. This paper presents an acquisition system developed by the authors, using a high performance GPS device, available on the market, a portable mini-computer and dedicated software. The GPS sensor is one oriented to OEM users, for machine operation and guiding and agricultural applications. The sensitivity is very high and the registration rate is 5 Hz. It is connected to a computer through serial interface. The software application developed for this system takes the information from the GPS sensor using the sentences defined by the NMEA messages standard. Information about position, velocity and acceleration are displayed in real time on the computer screen and all useful data acquired are saved in a text file. These data are imported then in a special CAD application, for post-processing. The system was used in various studies regarding vehicle dynamics or efficiency and in traffic or noise analysis.

Keywords: data acquisition, instrumented vehicle, GPS, programming

1. Introduction

Navstar-GPS is the Global Navigation Satellite System developed by US Department of Defense, originally for military applications but with significant benefits for civil users. As all the existent satellite navigation systems (including Galileo and Glonass), GPS is composed by three segments: the space segment, the control segment and the user segment. The space segment consists in the satellites transmitting information about their position. The ground control segment transmits the location parameters, controls the paths and the data transmitted and changes the satellite orbits. The user segment consists in all the GPS devices that receive simultaneously the signal from the visible satellites and calculates the solution of the navigation equation, PVT (Position, Velocity and Time). The signals from at least four satellites are needed to obtain the solution. Based on the satellites navigation parameters it is possible to calculate the distances between each satellite and the GPS receiver [8].

Using a GPS receiver installed on a rigid body (like an automobile) it is possible to ascertain his position on Earth. Having two or three receivers (or a dedicated receiver with two or three antennas) on the same rigid body, it is possible to ascertain the orientation, on a plan or in 3D space.

The determination of position using GPS can be affected by some errors, like: orbital errors (also known as ephemeris errors, these are inaccuracies of the satellite's reported location), ionosphere and troposphere delays, signal multipath (occurring when the GPS signal is reflected off objects such as tall buildings or large rock surfaces), receiver clock errors (a receiver's built-in clock is not as accurate as the atomic clocks onboard the GPS satellites), errors caused by reduced or changing number of satellites, satellite geometry/shading (this refers to the relative position of the satellites at any given time).

Because of these errors, the absolute coordinates on the ground are calculated with an accuracy given in meters. However, it is possible to obtain high accuracy (centimetres or millimetres) in relative coordinates (using two receivers) or by receiving a correction (differential) signal from a fixed station (DGPS).

2. GPS receivers

The block diagram of a GPS receiver [4] is shown in figure 1.

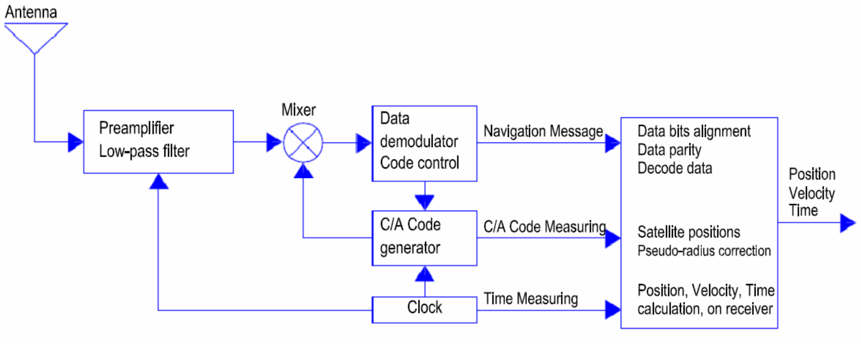


Figure 1. Simplified block diagram of a GPS receiver

Basically, the signal received by antenna is taken by a preamplifier with a low-pass filter, to reduce the higher frequency noise and to amplify the useful signal, with a carrier frequency over 1 GHz. The signal is then mixed with the *C/A* code generated locally and introduced in a demodulator for extracting the navigation data.

The GPS satellites transmit signals on two carrier frequencies, offering two levels of service: SPS and PPS. The SPS (*Standard Positioning Service*) signal is received by most of the commercial devices. The quality of the SPS signal may be altered intentionally by the US *DoD* (*Department of Defense*). The SPS signal is transmitted on the f_1 frequency, which is 1575.42 MHz. The PPS (*Precise Positioning Service*) signal offers higher accuracy and it was initially reserved for military and special applications.

The signal is transmitted on the f_2 frequency, which is 1227.60 MHz, and it is used for ionosphere and troposphere delays measurement.

The two carrier frequencies are phase modulated using three binary code signals:

- The *C/A* (*Coarse Acquisition*) code modulates the phase of the f_1 carrier;
- The *P* (*Precise*) code modulates both carriers, f_1 and f_2;

The navigation message modulates also the f_1 carrier signal. The navigation message is a 50 Hz signal consisting in data bits describing the GPS satellite orbits, the time corrections and other system parameters.

At reception, based on the three signals, the PVT (Position, Velocity, Time) information is calculated and sent further to the navigation device, using NMEA or similar protocols.

The GPS receivers can store data in their own non-volatile memory (like *SD* cards or *CompactFlash*), in text files using a *txt* or *gpx* format, or they can send data to other devices using RS232 or USB interfaces and a certain transfer protocol.

The most known transfer protocol used for transmitting GPS data is the standard recommended by NMEA (National Marine Electronics Associations). The NMEA 0183 standard [7] defines the requirements for the electric signal and for the data transmission protocol, and also the specific instructions format for a serial data bus of 4800 baud rate. For higher transmission rates (up to 38.4 kBd) it was defined an extension of the protocol, NMEA 0183-HS (High Speed). The NMEA standard is not intended only for communication with the GPS devices, but also for other electronic devices used in marine applications.

A NMEA sequence consists in a character string composed by a type identifier and more data fields, comma separated. The type identifier is used at reception for establishing the type and format of the data sequence that is to be read. The number and length of data fields depends by the sequence type.

Data taken from GPS include the geographic coordinates (longitude and latitude) and the altitude, used to position the receiver on the earth surface. The geographic coordinates must be converted in rectangular coordinates (x, y, z), in order to use them in the automotive kinematics studies. This operation can be done using dedicated software.

3. Use of GPS devices for data acquisition

GPS position relies on precise measurements of the distance from the receiver to the satellite and is affected by numerous effects which can reduce the quality of the signal, like atmospheric conditions or reflections from nearby objects such as buildings which introduce multipath, again adding to the length of the signal. The speed calculated as changes of the position in time will give a “noisy” result, as in Fig. 2, left side. Interpolation of the values obtained this way will affect the accuracy which is very important when testing the vehicle's performances.

However, GPS velocity can be measured using a different method which measures the change of the signal from satellite, or Doppler Effect. By measuring this change, the errors which normally affect GPS have very little influence over the quality of the signal, and the velocity measurement is phenomenally accurate. Another great aspect of GPS is that all satellites have atomic clocks on-board, and by utilising this signal, the timing remains stable to within less than a millionth of a second [10].

Therefore, instead of using position to measure distance, the accurate Doppler derived velocity is integrated using the precise time signal to derive distance. The result of the combination of these two is an extraordinarily accurate distance measurement. An example result is in Fig. 2, right side.

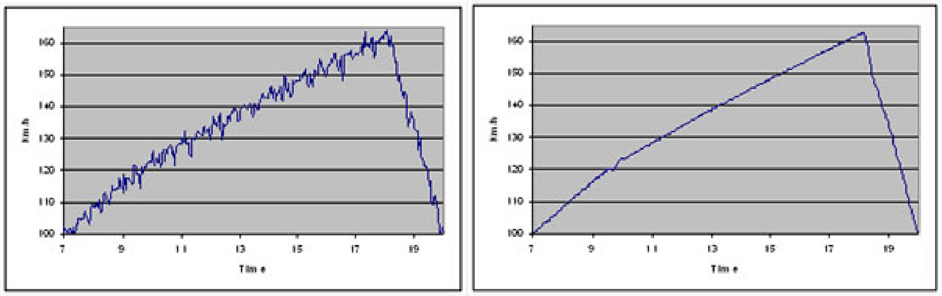


Figure 2. Velocity calculated from position and time information (left), and using the Doppler Effect (right) (source: http://www.racelogic.co.uk)

It is preferred to read the velocity directly from the GPS receiver, whenever is possible (eg. by reading NMEA sequences), instead of calculating the velocity based on successive positions.

To measure the dynamic performances of a vehicle, no matter what instruments or tools are used, it is required to install these instruments on the vehicle and to collect data on the move. The traffic data can be also collected either by using instruments installed on moving vehicles (*instrumented vehicle* or *chase vehicle*) [1].

The process of data acquisition and processing is shown schematically in Fig. 3. Data collection phase is contained in two blocks in the first column and consists in the instrumented vehicle method.

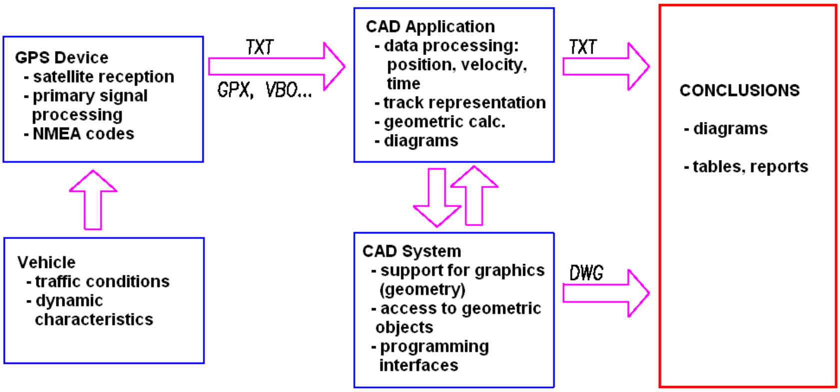


Figure 3. Flow diagram of data acquisition and processing

The instrumented vehicle is a vehicle with data acquisition equipment installed. When using GPS devices as data acquisition equipment, only those data related to that vehicle behaviour will be recorded.

Some of the advantages of the instrumented vehicle method are as follows:

- There is not necessary equipment installed on various places on the route (radar, inductive loop, video camera);
- Speed is recorded for the entire route length, not only in a single point (like when using external speed sensors);
- It can be ascertained also the acceleration, since the record is continuous in time;
- The time needed to collect data on different routes is shorter;
- It can be obtained an accurate velocity field on the travelled routes.

The preparation of instrumented vehicle consists in installation of data acquisition equipment. In the case of GPS devices, depending by their type, the most complex installation procedure consists in placing the external antenna on the vehicle roof, connecting the computer and starting the devices and software applications.

The use of GPS devices for data acquisition has some important advantages:

- Collect real data for the vehicle on which the device is installed;
- Simultaneously obtain time and grade information;
- Possibility to associate the collected data to a certain area, based on the digital maps, and automatically associate data with the density of population;
- Possibility to record many points on various tracks;
- Easiness of devices' use and installation, on any vehicle.

Some disadvantages of using GPS data acquisition are:

- Areas without satellite signal (canyons, tunnels);
- The GPS devices accuracy depends by a third-party technology (selective availability, controlled by DoD, the need for terrestrial station to have differential signal).

4. The new data acquisition system (DS-5)

Based on the Garmin GPS 18x-5Hz receiver [6], it was developed an original tool for vehicle dynamic behaviour analysis (called DS-5) [2], [9]. The system has two main components: hardware and software. The hardware part (fig. 4) consists in the GPS receiver, a minicomputer and the connecting interface, usually a RS232-USB adapter. The software part is a stand-alone computer program developed by the authors in Delphi programming language. The program is used for data acquisition and for storing that data as text files on the computer.

4.1. DS-5 Hardware

The system is composed by the GPS receiver, the interface and the minicomputer. Depending on the chosen minicomputer, sometimes may be necessary to use also an inverter, for plugging the computer to the vehicle 12 V outlet.

The receiver's power supply is not the vehicle's 12V outlet (this can be used as power supply for the computer). Instead, it is used one of the computer USB connectors as a 5 volts power supply. The advantage of using the computer's USB interface is that the computer battery is also a power back-up for the GPS receiver. Since the minicomputers (tables PCs) does not have an RS232 interface, it must be used an adapter cable between the computer USB connector and the device connector.

The GPS receiver is the Garmin GPS 18x-5Hz device. This device has a connecting cable terminated as bare wires and it has to be connected to a RS232 interface.

Figure 4. GPS 18x-5Hz and the DS-5 data acquisition system

GPS 18x-5Hz (Fig. 4) is a GPS sensor used especially for machinery operation and guiding, and for different agricultural applications, where are required very precise position and velocity information [6].

GPS 18x-5Hz has 12 parallel channels (is able to process simultaneously the signals received from 12 satellites), it is WAAS enabled (can process the differential radio signal when available) and has an integrated magnetic base. It has a permanent memory for storing the configuration information, an internal clock (independent by the satellite signal) and measured raw data, for high precision and dynamic applications.

The receiver sensitivity is -185 dBm. It is also available a function for generating an output pulse signal (*Measurement Pulse Output*) of 5 Hz, with the superior limit aligned with offsets of 0 ms, 200 ms, 400 ms, 600 ms and 800 ms from the signal front that mark the UTC seconds, in 1 microsecond interval, for all cases when the GPS receiver reports a valid and accurate positioning in a period of at least 4 seconds.

The GPS 18x-5Hz device does not work independently; it must be connected to a computer.

Of high importance is the transfer rate through the serial interface, because this influences directly the data acquisition rate from the GPS device. To ensure reception of all information at intervals of 0.2 seconds, the transfer rate should be 19200 bauds. There are not needed all the NMEA data sequences that the GPS receiver is able to send, because the acquisition rate of 5 Hz may be affected (will be reduced to 2.5 Hz).

The device configuration influences the volume of received data in a measure given by the results of the simple relation below:

$$\text{Length of received sequence} = \frac{\text{(number of transmitted characters)}}{\text{(characters transmitted per second)}}$$

Ascertaining the required transfer rate (bauds) can be done using the above relation and the data given in Table 1 and Table 2.

Table 1 – Characters per second transmitted at various transfer rates

Transfer rate (bauds)	Characters per second
300	30
600	60
1200	120
2400	240
4800	480
9600	960
19200	1920
38400	3840

Table 2 – Transfer rate and sequence length for NMEA 0183

Sequence	Transfer rate	Max. characters
GPRMC	One / record	74
GPGGA	One / record	82
GPGSA	One / record	66
GPGSV	One / record	70
PGRME	One / record	35
GPGLL	One / record	44
GPVTG	One / record	42
PGRMV	One / record	32
PGRMF	One / record	82
PGRMB	One / record	40
PGRMT	One / minute	50

The useful NMEA sequences that should be taken from the GPS receiver are: *$GPRMC* (includes position data, speed in knots, time), *$GPGGA* (3D position and accuracy – quality of the signal, number of satellites) and *$GPVTG* (heading and ground speed in knots and km/h) [7], [2], [3].

Maximum number of characters to be transmitted is:

$$74 + 82 + 42 = 194.$$

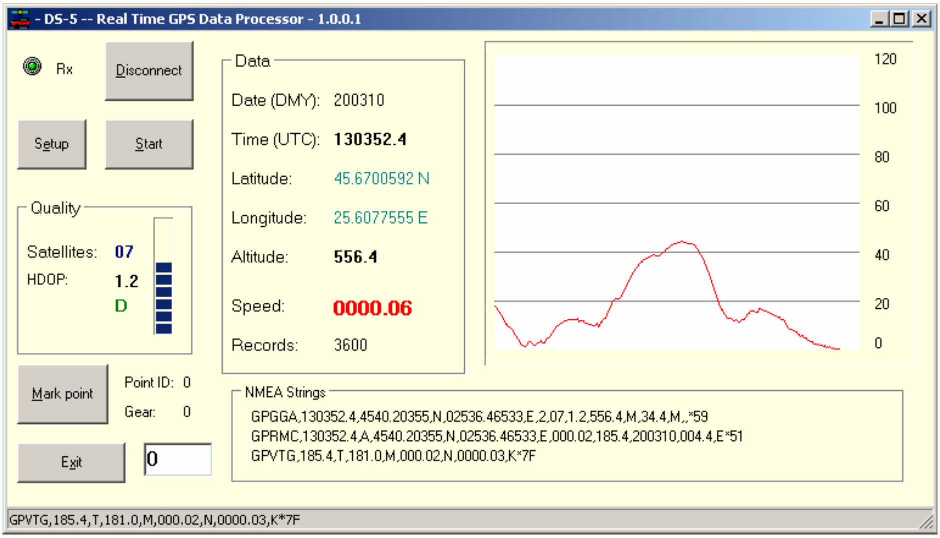
In this case a baud rate of 2400 bauds is needed to transmit one record per second, and for 5 records per second (5 x 194 = 970 characters) is required a rate of 19200 bauds.

The useful data taken from receiver are: time (with a rate of 0.2 seconds and the accuracy given by satellite), latitude, longitude (both in degrees, with 7 decimals accuracy), altitude (accuracy of 0.1 meters) and velocity (accuracy: 0.01 km/h).

Additionally, as coordinates accuracy information, there are known: the satellites number (in good receiving condition there are 8-10 satellites visible) and *HDOP* (*Horizontal Dilution of Precision*) – usually less than 1.5 (with differential signal: < 1).

4.2. DS-5 - Software

For the acquisition, primary processing and saving of received data with *DS-5* (based on GPS 18x-5Hz) it was developed a dedicated software application using Delphi programming language. It was chosen this programming environment because it features dedicated objects for creating flexible and easy to use user interfaces. In addition, libraries are available with predefined functions dedicated to various kinds of applications, including serial port programming (RS-232). So it was possible to write the user interface shown in Fig. 5.



Satellites: 07
HDOP: 1.2
D

Point ID: 0
Gear: 0

0

Date (DMY): 200310
Time (UTC): 130352.4
Latitude: 45.6700592 N
Longitude: 25.6077555 E
Altitude: 556.4
Speed: 0000.06
Records: 3600

```
GPGGA,130352.4,4540.20355,N,02536.46533,E,2,07,1.2,556.4,M,34.4,M,,*59
GPRMC,130352.4,A,4540.20355,N,02536.46533,E,000.02,185.4,200310,004.4,E*51
GPVTG,185.4,T,181.0,M,000.02,N,0000.03,K*7F
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GPVTG,185.4,T,181.0,M,000.02,N,0000.03,K*7F
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Figure 5. User interface of the GPS data acquisition software

The main areas in the user interface (the main screen of the program) are:

- *Data* – display in real time the information received from the GPS sensor; when the satellite signal is not available (not enough visible satellites), the coordinates displayed in this field are taken from the internal memory of the device;
- *Quality* – information about quality of the signal, like the number of visible satellites and *HDOP* (*Horizontal Dilution of Precision*); when differential signal is available, a „D" appear also in this area;
- *NMEA Strings* – the NMEA sequences received from the GPS sensor; these strings are displayed in order to have an additional control of the data received, especially in the software development phase;
- The graphic area (white area on the right side of the screen) – here is displayed, in real time, the speed versus time diagram, when data logging is enabled;
- Marking area (bottom-left) – includes the „*Mark point*" button; by clicking on this button the current position is recorded and also the edit box „*GEAR*", where it can be entered the current transmission gear (numeric keys, from 0 to 6);

- The control area (upper-left) – in this area are placed the buttons for configuration, connecting to the GPS device and start/stop the recording; the buttons are big enough for easy use with a Tablet-PC with touchscreen.

5. Performances of the DS-5 data acquisition system

In order to check the influence of the measurement errors on the collected data, numerous tests were made. These tests can be grouped as follows:

- Measurements with GPS receivers stationary for a long time (minutes);
- Recording the same track with the same receiver at different times (in the same day or different days);
- Simultaneous recording of the same track with two GPS receivers, of same or different models;
- Simultaneous recording of the same track with the GPS receiver and other type of measuring device.

The influence of atmospheric condition and obstacles may be revealed by recording the position of a stationary receiver. The results measured with a stationary *GPS 18x-5Hz receiver* are shown in Fig. 6. Both records were taken in the same position, for 30 seconds and 100 seconds, respectively. The number of satellites was 8 for the first measurement, and 7-8 for the second measurement. The accuracy reported by the receiver through *NMEA* sequences (*HDOP – Horizontal Dilution Of Precision*) was 0.9 – 1.2, values which generally indicate a good accuracy. According to Fig. 6, with these measurements it was obtained a positioning precision of 0.342 - 0.475 meters.

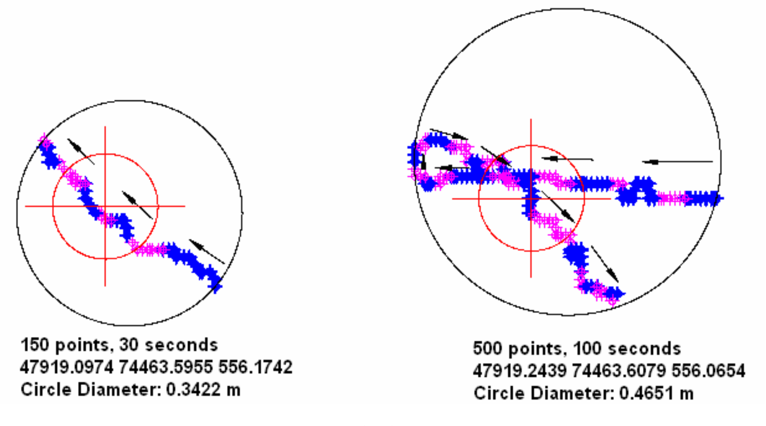

Figure 6. Measurements with the GPS receiver stationary [2]

For testing the *DS-5* system on a moving vehicle, the vehicle having the new system activated simultaneously with a GPSmap 60CSx system [5] was driven on a short track, with a total length of 500 metres, Fig. 7.

In Fig. 8 is presented the speed versus time diagram for the same track (Fig. 7) recorded with both devices. As it can be seen in this diagram, the two signals are not perfectly synchronized (the GPSmap signal is delayed with one second). The difference is caused by the internal processing of the GPS signal by the microcontroller embedded in the GPS device, which also make a filtration of the position.

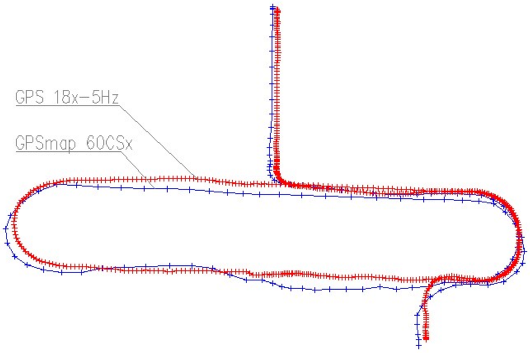

Figure 7. 500 m track recorded with two different devices: GPSmap and DS-5

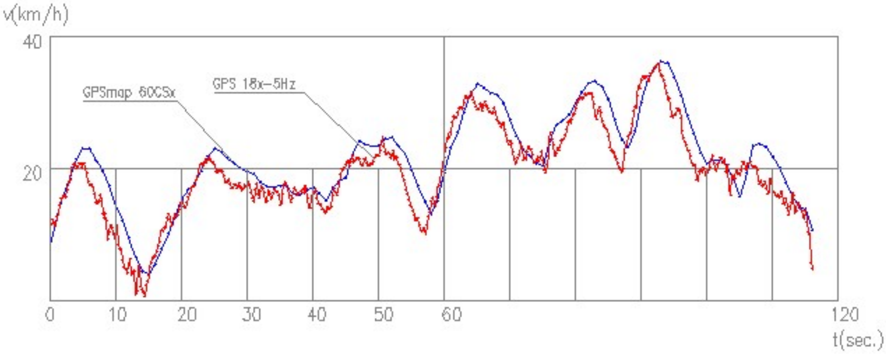

Figure 8. Time/Speed diagram for two different devices: GPSmap and DS-5

Figure 9. Part of a track recorded with Vbox and DS-5, simultaneously

The speed computation was based on the successive positions recorded at the time interval allowed by each device: 1 s (GPSmap) and 0.2 s (GPS 18x), respectively. The noise (signal discontinuity) in the diagram of speed recorded with GPS18x in Fig. 8 (the red curve) will not appear if the speed is read from the device, using the NMEA codes.

Another comparison was made between DS-5 and Vbox III, a professional data acquisition system made by Racelogic [10]. Fig. 9 presents a part of a track, recorded with both devices. It is obvious a pretty high deviation from the route of the track recorded with Vbox, device which was expected to be more accurate than GPS 18x, in similar conditions. The speeds versus time diagram, and also speed versus distance, are shown in Fig. 10.

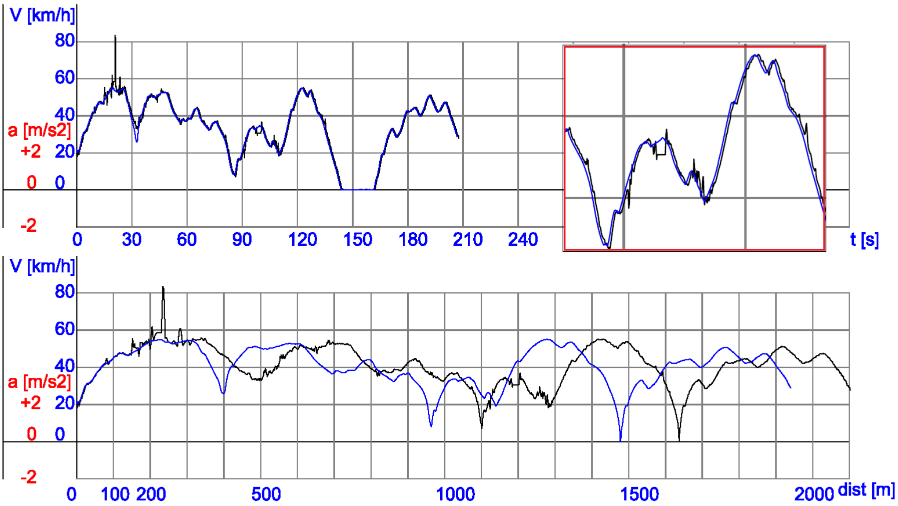

Figure 10. Time/Speed diagram (top) and Distance/Speed diagram (bottom), measured with Vbox (black) and DS-5 (blue)

The deviation from the route of the track recorded with Vbox does not seem too big and it would not be a problem if the objective would be guiding the driver, based on a digital map. But the speed versus distance diagram reveals important differences. In Fig. 10 the speed recorded with Vbox is represented in black, and the speed recorded with GPS 18x (DS-5) is presented in blue. In both cases the speed is read directly from the receiver, not calculated from successive positions and time. First, the time/speed diagram shows the records' synchronization, but the Vbox records present some unrealistic deviations. These deviations do not seem to be just a recording noise, as in Fig. 2. In the distance/speed diagram the differences are too high (more than 5% difference between the two records, for the total length of the track – Fig. 10), and are caused probably by the positioning errors – the distance between successive points is ascertained based on the recorded positions.

The source of the positioning errors of the *Vbox* system seems to be the reduced number of visible satellites; *Vbox* has received signals from 5-6 satellites, since *GPS 18x* has received signals from 7-8 satellites. The test was made inside a city, on a "*canion*" road, with high buildings on both sides. The errors given by Vbox is explainable, but in the same time the quality of signal reception of *GPS 18x* is remarkable.

6. Conclusions

DS-5 is a low cost data acquisition system, based on GPS technology. The performances are good enough for analysis of vehicle dynamic behaviour, but can be used also for collecting traffic data [1].

The DS-5 system has two components: the hardware equipment and the software application. The hardware is realized by putting together elements available on the commercial market: a high precision GPS sensor and a small size computer. The software component is an original application developed by authors [2], [3].

The precision given by the GPS device (GPS 18x-5Hz) is as high as 7 decimals for longitude and latitude, 0.1 meter for altitude and 0.01 km/h for speed. The data sequences are transferred from the GPS device at a rate of 5 samples per second (0.2 seconds time period); the time accuracy is given by satellites. The accuracy of recorded data is indicated by the number of satellites (8-10 satellites are available in good weather conditions) and by the *HDOP* parameter. *HDOP* is usually less than 1.5 and can be even less than 1 when differential signal is available [3].

Although the positioning accuracy is increasing continuously, the errors remain an important problem, quite difficult to control, especially in reduced satellites visibility. However, a proper use in correlation with quality processing-algorithms permits to the GPS systems to provide a precision of speed and acceleration measurements at least as good as other measuring systems used in experimental research.

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