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DATA RECORDING SOLUTIONS FOR VEHICLE TESTING

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Abstract: *To date, vehicle motion data logging is often done using GPS receivers. The motion parameters are useful for studies related to vehicle dynamics, road traffic and even road events reconstruction. Depending by the goal of the study, different data loggers with different parameters may be used. Commercial low cost devices can be used for collecting traffic flow data, when the sampling rate can be low (1 sample/second), but professional high speed devices are required for braking tests or crash tests. In this paper are presented some devices used for data logging in road traffic as well as in the study of the vehicle dynamics.*
Keywords: *data acquisition, GPS, vehicle testing*

1. INTRODUCTION

GPS devices are widely used not only for navigation and to measure vehicle's speed, but also to estimate the driver behavior, vehicle dynamics performances or traffic flow parameters. Depending by application, some devices may be less or more appropriate. As shown in previous studies (like [1]), the characteristics required for a GPS device used for traffic studies are different than for those used in vehicle testing. A versatile device, based on a receiver with 5 Hz sampling rate was presented in [2] and [3]. Data from GPS receiver is transmitted to another device (like a computer or data logger) as string sequences, using NMEA 0183 protocol. When collected data are used for statistical analysis (traffic studies), a sampling rate of 1 Hz is just enough, up to 5 Hz is better. A higher rate will increase too much the processing time. In vehicle dynamics applications, the total time of a test is shorter, but a higher sampling rate is required.

For critical vehicle testing applications, the sampling rate should be higher than 20 Hz ([5], [6]) and 100 Hz sampling rate is usually offered by professional testing systems like SpeedBox. The accuracy is improved by integrating IMU devices with the GPS receiver [4]. Inertial sensors are used to help with dead reckoning, since they provide very accurate directional information, but also for analysis of the vehicle lateral dynamics and for improving the accuracy in brake tests.

Less demanding tests can be performed with GPS receivers with a sampling rate between 5 and 20 Hz. Examples are the coast-down test, and generally low speed tests.

In this paper are presented some low cost GPS receivers, tested in similar conditions, at the speeds normally used in urban traffic. Beside these, a SpeedBox [5] device was used as a reference, configured to work similar with the other receivers.

2. DEVICES USED

2.1 SpeedBox

The SpeedBox system (Fig. 1) is a GPS-Inertial measurement system from Race-

Technology [5]. It combines data from GPS and inertial sensors to provide a full 200 Hz speed update rate with outputs on RS232, CAN, digital pulse or analogue. The RTK option enables SpeedBox to provide high accuracy slip angle, pitch and yaw measurements.

Fig. 1. SpeedBox (general arrangement)

SpeedBox includes high resolution analogue inputs/outputs, CAN bus output, and dual serial ports. All inputs and outputs are configurable from the dedicated PC software.

SpeedBox is designed to be used as a sensor head either for direct connection to a PC or to an additional data logging system, where accurate real time speed measurement is required, mainly in automotive applications.

The standard features of the device are:

- High accuracy 200 Hz speed output (using the inertial sensor)
- 20 Hz GPS speed and position output
- 3 Axis acceleration measurements
- Optional internal IMU
- Dual serial ports (3 output modes)
- CAN output port
- 4 x Analogue input / output ports
- Brake / event trigger input
- Wide 7-30 V supply range
- Extremely low latency (2-3ms)
- Low power (3 W).

The characteristics of the SpeedBox system are much over the other devices used (2.2 - 2.4), but in order to compare the results, using SpeedBox as a reference, the unit was configured to output GPS data as NMEA sequences, at a 10 Hz sampling rate, and the output from inertial sensors was disabled. The data was logged on a PC, since another logging system, dedicated for use with SpeedBox, was not available. The software used for data logging with SpeedBox (using NMEA sentences) was the same as for GPS 18x-5Hz, described below.

2.2 GPS 18x-5 Hz

GPS 18x-5Hz (Fig. 2) from Garmin is a GPS sensor used mainly for machinery operation, guiding and different agricultural applications, where are required very precise position and velocity information [7].

Fig. 2. GPS 18x-5Hz

Some features of GPS 18x-5Hz are:

- 5 Hz sampling rate
- velocity accuracy: 0.1 knots
- velocity resolution: 0.01 knots
- receiver sensitivity: -185 dBW (-155 dBm)
- interface: RS-232 asynchronous receiver, 19200 bauds by default.

The GPS 18x-5Hz device does not work independently, it must be connected to a computer. The receiver sends the data through the RS-232 interface, as NMEA sequences. The receiver was integrated in the DS-5 system, described in [1], and the information is stored in a text file.

2.3 u-Blox 5

The receiver used was GS407 U-Blox5 GPS 4Hz which is based on the uBlox 5 chipset with a Sarantel helical antenna (**Fig. 3**).

Fig. 3. GS407 U-Blox5

The sampling rate is 4 Hz. Other features include [9]:

- receiver sensitivity: -160 dBm
- velocity accuracy: 0.1 m/s
- velocity resolution: 0.001 knots
- interface: RS-232, 9600 bauds.

The protocols that can be used are u-Blox proprietary and NMEA 0183.

The u-Blox 5 receiver is included also in the Trek 550 system from Advantech (which is an in-vehicle computing box) [10]. The receiver works also with the software interface of the DS-5 system, saving processed NMEA data in text files.

2.4 Venus 634

The Venus634FLPx receiver (from SkyTraq Technology) is a module-in-a-chip design for mobile consumer. It has very low current consumption, high sensitivity, high signal acquisition and time-to-first-fix performance.

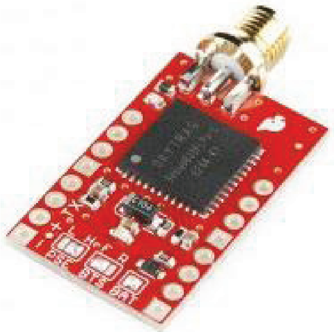


Fig. 4. Venus GPS with SMA connector

The sampling rate is up to 10 Hz (and up to 20 Hz in case of Venus 638). Other features are [11]:

- tracking sensitivity: -161 dBm
- velocity resolution: 0.1 knots
- interface: RS-232, 9600 bauds by default.

The Venus receiver uses the NMEA protocol to transmit data through the serial interface.

2.5 Mod-GPS

The Mod-GPS smart receiver [12] (Fig. 5) is a total solution GPS receiver designed based on high-sensitivity SiRF Star III architecture.

Fig. 5. Mod-GPS

Some key features are:

- 1 Hz sampling rate
- tracking sensitivity: -159 dBm
- velocity resolution: 0.01 knots
- reacquisition time: 0.1 sec.
- RS-232 interface (19200 bauds).

Mod-GPS is a very compact and easy to use device.

2.6 Data loggers

All the receivers presented transmit data using the RS-232 serial interface. The signal can be received using the serial port of a computer (like in the case of DS-5), or another logging device. The advantage of using a computer is that the user has full control over the data acquisition process, and can change the configuration when the field conditions require. On the other hand, the use of a small and compact data logger has the advantages of compactness, smaller power consumption, and easiness of use.

One of the loggers used was Logomativ v2, from Sparkfun [13].

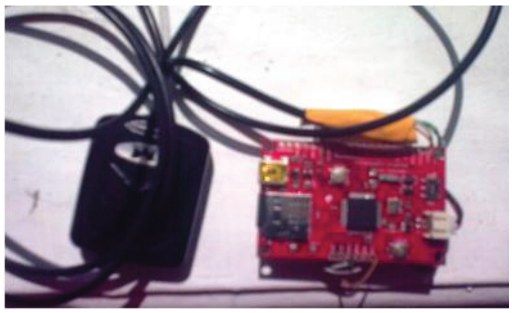


Fig. 6. Mod-GPS connected to Logomatic v2

Logomatic v2 includes a microSD card slot and RS-232 interface. In Fig. 6 is an example of using Mod-GPS receiver with Logomatic v2 data logger.

All the data received through the RS-232 interface are stored on the microSD card. The result is one or more text files containing NMEA sequences.

Another logger used was OpenLog (Fig. 7), a small device based on the controller Atmega328 [13]. It has also a microSD slot and when is powered it starts logging all data received through the serial port.

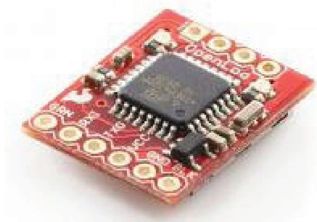


Fig. 7. OpenLog

Both these loggers are configured by changing the content of a configuration file, stored also on the microSD card.

The loggers and the GPS receivers use the same LiPo battery as power supply. In case of using a PC for logging data, the GPS receiver is powered through the USB interface.

2.7 NMEA 0183 Protocol

The protocol used to transfer data between the GPS receiver and the data logger is NMEA 0183. This protocol consists in string sentences used to communicate between two devices.

From the GPS device, the sentences are transmitted with respect to the user selected baud rate. The logging device must be configured to use the same baud rate. The NMEA sentences used depends by the user selection. Usually, there are not needed all the NMEA sequences that the GPS receiver is able to send; in order to use a high sampling rate, the number of NMEA sequences should be reduced to a minimum.

The minimum data needed for automotive applications are $GPRMC (includes position data, velocity in knots, heading, time) and $GPGGA (time, 3D position and accuracy – quality of the signal, number of satellites). Example of data received from Mod-GPS and stored in text file:

```
$GPRMC,143314.000,A,4538.6166,N,0253
5.8133,E,0.05,38.87,080714,,,A*50
$GPVTG,38.87,T,,M,0.05,N,0.10,K,A*0D
$GPGGA,143315.000,4538.6161,N,02535.
8135,E,1,4,1.58,569.5,M,35.4,M,,*5C
```

(and also the $GPGSV sequences are stored).

From the saved data, the post-processing software will use only the needed sequences.

When the receivers are used with a PC and data is processed in real time using the DS-5 software component, the resulted file contains information like this:

```
25.6351460,45.6397008,599.0, 07:28:20.0
2014,0000.01,07
25.6351460,45.6397008,599.0, 07:28:20.2
2014,0000.01,07
25.6351460,45.6397008,599.0, 07:28:20.4
2014,0000.01,07
25.6351460,45.6397008,599.0, 07:28:20.8
2014,0000.01,07
25.6351462,45.6397008,599.0, 07:28:21.0
2014,0000.01,07
```

Depending on the number of the sequences received for each point, the baud rate should be set at a higher value. When the configuration software of the receiver allows, only the required NMEA sequence types will be sent to the logging device.

3. COMPARATIVE TESTS

The receivers presented above were used to collect data on a vehicle, equipped with at least two of these receivers at the same time. The recorded tracks (stored as text files) were then processed using dedicated software developed in-house, under AutoCAD environment (that means the geometric functions of the CAD system were used). Each record corresponds to a geometric point in CAD, and the associated data (like speed, time, acceleration, geographic coordinates) are attached to the point as custom data.

Table 1

Some characteristics of the GPS receivers used

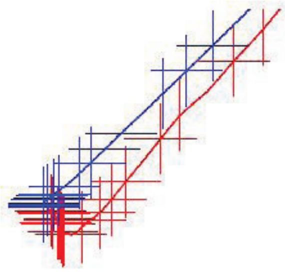
Receiver	lat/long resolution (deg)	Speed resolution (knots)	Altitude resolution (m)	Sampling rate (Hz)
GPS 18x-5Hz	0.0000001	0.01	0.1	5
u-Blox5	0.0000001	0.001	0.1	4
Venus 634	0.000001	0.1	0.1	10
Mod-GPS	0.000001	0.01	0.1	1
SpeedBox (NMEA)	0.0000001	0.1	0.001	10

Despite the sampling rate of 10 Hz, the Venus 634 receiver does not have the features to offer enough accuracy for vehicle dynamics tests (like accelerating, braking, steering). The default setting is at 1 Hz and the configuration software is not so stable and easy to use, making the change of the configuration difficult. Like Mod-GPS, this receiver is also more appropriate for traffic data collection. The loggers tested with both these receivers were Logomatic and OpenLog.

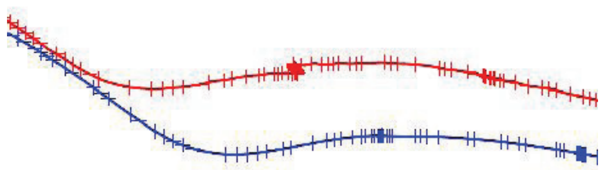
The receiver u-Blox5 has some good characteristics (resolution, sampling rate, accuracy) and if is combined with IMU sensors the system can be used for dynamics tests.

A direct comparison of the receiver's characteristics is not relevant, since these are not measured by an independent laboratory. All the data given above are taken from the receivers specifications. For example, in practice, the sensitivity of the receiver is not in direct relation with the number of satellites in view. The absolute position is not as important as it is the relative position of a point in the track. This make the resolution of the geographic coordinates more important than the absolute positioning accuracy.

A track can be represented based on the geographic coordinates extracted from each record, or based on speed and heading. The coordinates must be transformed from a geographic system (like the WGS84 datum) in a cartesian system, which is specific to the location where the track was recorded. For the second type of representation, a starting point is needed, and this can be taken also from the geographic coordinates, but if the track will not be georeferenced the starting point can be chosen in the origin of the coordinate system, or anywhere. Having the time between two records (in seconds), the speed (converted from knots in m/s) and the heading (direction of traveling, in degrees, with 0 degrees to the North), each point can be determined with his polar coordinates.



a)



b)

Fig. 8. Representations of a track based on the geographic coordinates (red) and based on speed and heading (blue)

An example representation (details from a track) is given in Fig. 8. It is the same track registered using Mod-GPS as receiver, represented in two ways: in blue with coordinates calculated from speed/time and heading, and in red with coordinates calculated from the geographic coordinates of each point. Each representation has disadvantages, and eventually the accuracy of representation depends by the accuracy of the GPS receiver.

A driving test was done on an urban route, using the receivers u-Blox5 and GPS 18x-5Hz on the same vehicle, at the same time. A map representation of the registered track is given in Fig. 9 and the full track represented in a CAD environment (AutoCAD, using some original developed AutoLisp functions) is given in Fig. 10 and Fig. 11 (which contains the detail marked with a circle in Fig. 10).

Fig. 9. The registered track shown in Google Earth

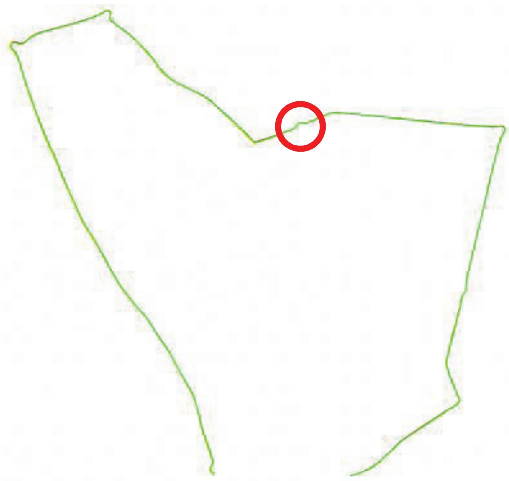


Fig. 10. The registered track represented in AutoCAD

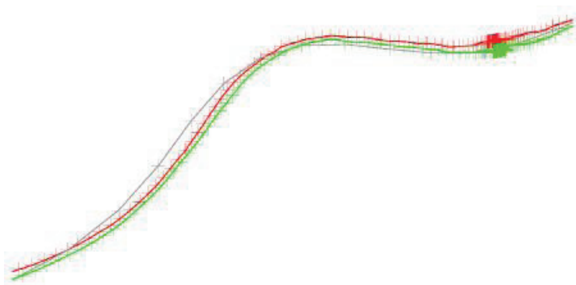


Fig. 11. Detail from the registered track (AutoCAD)

The logging system was in this case the in-vehicle computing box Trek-550 from

Advantech, using the internal u-Blox5 receiver and also two external GPS 18x-5Hz receivers connected through the available serial interfaces (Fig. 12 and Fig. 13).

Fig. 12. The three GPS antennas on the vehicle roof

Fig. 13. The logging system (Trek-550 back panel with multiple RS-232 ports, assisted by a tablet-pc as smart display)

The whole track has about 8 km length and the travel time was about 15 minutes. As a result of data processing are presented the diagrams in Fig. 14 (detailed in Fig. 15). These diagrams show the variation of speed and acceleration of the vehicle, versus time (top diagrams) and distance (bottom diagrams). As can be seen, especially in the detailed representation, there are no significant differences between the speed diagrams, but some differences are easy to see in the acceleration diagrams. These are given mainly by the difference of the sampling rate (4 Hz and 5 Hz).

The speed values are obtained directly from the NMEA sentences, being measured by GPS receivers using also the Doppler effect. In this way the values are more accurate than when are calculated from successive positions and time (*dx/dt*). Instead, the instantaneous values of the acceleration are obtained using

$$a = \frac{dv}{3.6 \cdot dt}$$

where a is the acceleration, as derivate of speed, given in m/s^2, and the speed v is measured in *km/h*.

In order to ascertain and compare some traffic parameters, the data extracted from these diagrams can be analyzed using statistical methods. The values that are easy to calculate are the mean values, and also the median speed (named V50) and V85 (the speed not exceeded in 50% and 85% of records, respectively).

The well known formula used to calculate the average speed (and also for acceleration) is implemented in the custom software functions:

$$\bar{v} = \frac{1}{N}\sum_i N_i v_i$$

where $\bar{v}$ is the average speed, N_i is the absolute frequency of observations in the speed group i, v_i is the middle value of speed in the group i and N is the total number of observations ($N=\sum N_i$).

The values of V50 and V85 are obtained graphically, also using an automated software tool developed under AutoCAD. Examples of diagrams used are given in Fig. 16 and Fig. 17, for the GPS 18x-5Hz receiver. The diagrams for the u-Blox5 receiver are similar.

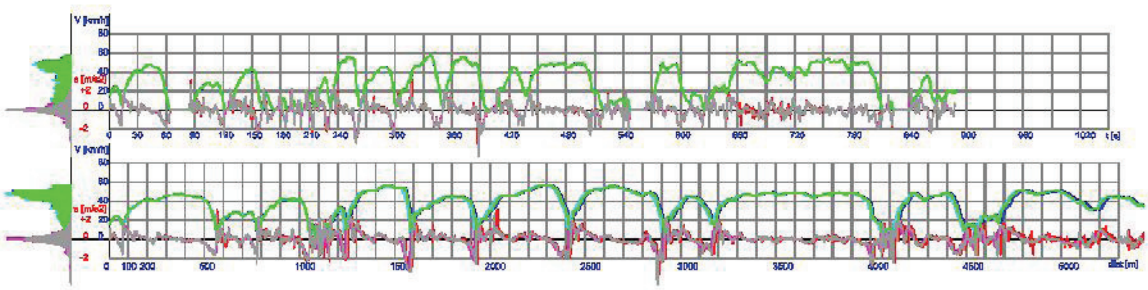


Fig. 14. Diagrams of speed and acceleration versus time (top) and versus distance (bottom) for the three receivers used - the grey diagram is for u-Blox5

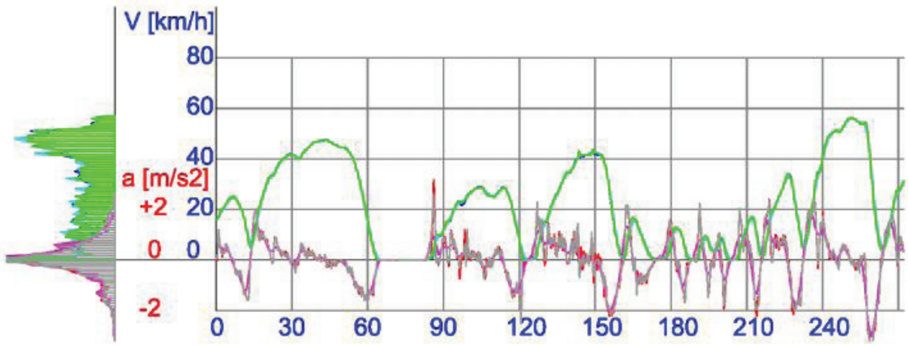


Fig. 15. Detail of the above diagrams (speed and acceleration versus time)

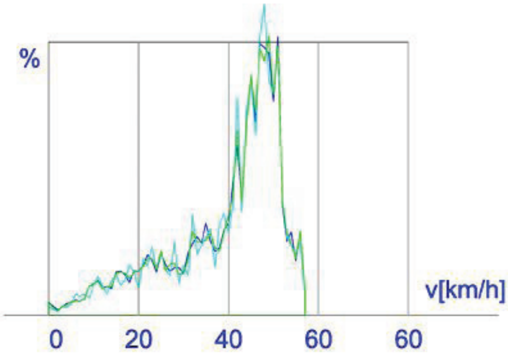


Fig. 16. Absolute frequencies of speed distribution

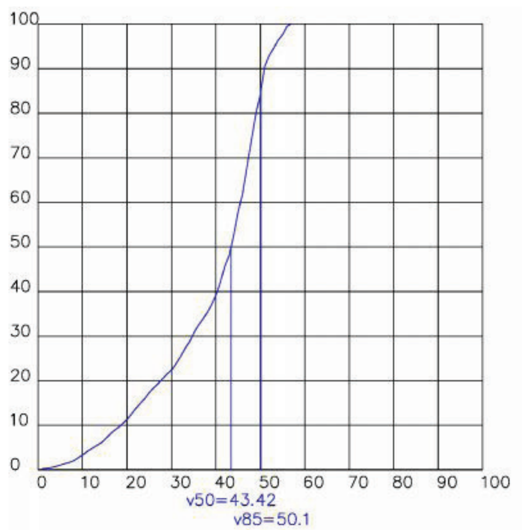


Fig. 17. Relative cumulated frequencies of speed distribution

In the table below are presented the V50 and V85 values calculated based on the speed distribution diagrams, for the three receivers.

Table 2

Traffic parameters V50 and V85

Parameter	18x-5Hz (first)	18x-5Hz (second)	u-blox5 (4 Hz)
V50 (km/h)	43.42	43.45	43.37
V85 (km/h)	50.1	50.07	50.01

The values in Table 2 are very close; the differences between the u-Blox5 and any 18x receiver are similar to those obtained between the two 18x receivers. So we can conclude from this experiment that both receiver types are appropriated, in the same measure, for precise determination of the traffic parameters in urban environment.

4. CONCLUSION

The choose of the GPS receiver to be used for data collection depends on the application and the parameters that must be calculated. An important characteristic of the GPS receiver is the speed accuracy, but the speed resolution is also important, in order to have precise readings for post-processing. A resolution lower than the reported accuracy will reduce the actual accuracy accordingly. The sampling rate is another important characteristic of the receiver and has a big influence on the type of tests that can be conducted using that device. Beside the receiver characteristics, the data transfer performances of the logging system are critical when the sampling rate is high. A rate of up to 10 Hz can be used with a serial interface at a baud rate of 19200 bps (higher is better). The simple loggers presented in this paper are appropriate for these applications, but for higher sampling rates with many parameters transferred to the logger, other interfaces and protocols should be used (like CAN Bus, for example). The receivers with a sampling rate of 1 Hz can be used with small loggers with RS-232 interface with a baud rate of 9600 bps, transferring GPS data as NMEA sequences, but only in applications where a large amount of data is needed for statistic analysis, typical examples being the calculation of traffic parameters.

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