MVT 2012XNNN

METHOD FOR ASCERTAINING THE ROAD SLOPE WITH APPLICATION IN ACCIDENT RECONSTRUCTION

Dragoş Sorin DIMA, Dinu COVACIU
Transilvania University of Braşov, d.dima@unitbv.ro, dinu.covaciu@unitbv.ro

Abstract: *The paper presents a new method for ascertaining the gradient of a road segment, based on measurements taken with GPS devices. The studied road was traveled with an instrumented vehicle, equipped with different GPS receivers, and then the data were processed using a custom software application. The reference for analysis was the existing project for rehabilitation of that road segment. Using the track measured is possible to generate the 3D road profile. The issue comes for all the experts in accident reconstructions, to have a more precise view on minimum equipment necessary to measure the road and to know from the beginning the estimation of error in simulation and reconstruction of the scene. This will be a helpful image on the estimation of total error induced in obtaining the final position.*

Keywords: accident reconstruction, road geometry, slope, GPS data acquisition

Introduction

In time, we have made many measurements on the dynamic behaviour of cars using different devices. The studies have been focused on the accuracy of the measuring system and the volume of data acquired [2, 3]. The road geometry was not so important at that moment. On the other hand, when measuring the road geometry using classical methods we got a good approximation. In the picture below (Fig. 1) is shown the 3D road profile generated in PC-Crash [6], of the road presented in the same picture.

Fig. 1: The real road and the road profile generated on the computer

The slope affects two resistances (drag) involved in the vehicle motion: the slope resistance and the rolling resistance. These can be ascertained using the following formulae:

$$F_r = f \cdot G_a \cdot \cos\alpha \quad (1)$$

and

$$F_p = G_a \sin\alpha \quad (2)$$

where:

- F_r is the rolling resistance, f is an estimation of the average rolling resistance coefficient, G_a is the vehicle weight and α is the road gradient;
- F_p is the slope resistance.

The rolling resistance is much more influenced by the f coefficient than the gradient, since the *cos* value is close to 1. So this drag depends more on the quality of the road, since the slope resistance depends more on the geometry of the road.

As the slope resistance depends by the sinus of the slope angle, an improper value of this angle may affect the estimated vehicle speed and the power needed to overcome the slope resistance. This may lead to an inaccurate reconstruction of an accident.

Here we propose a simple method for measuring the road slope (gradient) with a good accuracy and with minimal costs, in time and money.

Devices and methods used for data acquisition

The source of data for this study was a road segment for which it was available the design project for road rehabilitation and also a geodetic survey made using a total station. The equipment used for dynamic measurements on the road consisted in two professional GPS devices: Vbox III from Racelogic and DS-5, an in-house developed system based on the GPS 18x-5Hz sensor from Garmin.

Racelogic **Vbox III** (Fig. 2) is a professional device with a recording rate of up to 100 samples per second, able to compute speed and acceleration; it is designed especially for measuring the position and velocity of a moving vehicle [5].

Fig. 2: Racelogic VBox

The parameters that can be measured by VBox, based only on GPS signal and without any other external sensors are: velocity, distance, time, position, heading, altitude, lateral and longitudinal acceleration, vertical speed, turning radius, position on a road, track (record), coasting down distance. The data recorded data are stored on a *CompactFlash* card, as text files, in a specific format (*.vbo*).

DS-5 is a data acquisition system designed at Transilvania University, Department of Automotive Engineering. It is based on the sensor GPS 18x-5Hz (Fig. 3), manufactured by Garmin, designed for machinery operation, guiding and different agricultural applications, where are required very precise position and velocity information.

GPS 18x-5Hz [4] has 12 parallel channels and is WAAS enabled (can process the differential radio signal when available). It has an internal non-volatile memory for storing the configuration information, an internal clock (independent by the satellite signal) and measured raw data, for high precision and dynamic applications.

Fig. 3: GPS 18x-5Hz

The sampling rate is 5 Hz, much less than the rate of VBox, instead has a higher sensitivity. The receiver does not work independently; because his cable is terminated with bare wires - so it must be connected to a computer or another logger device. The DS-5 system [1] consists in the 18x receiver, a small, ultraportable computer with an adapter between receiver and computer, and the software application developed especially for this system (Fig. 4). The acquired data are stored as text files on the computer. Optionally, the receiver can be connected to a logger instead of a computer, to save data directly on a micro-SD card.

The useful data taken from the 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).

In addition, 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 may be less than 1).

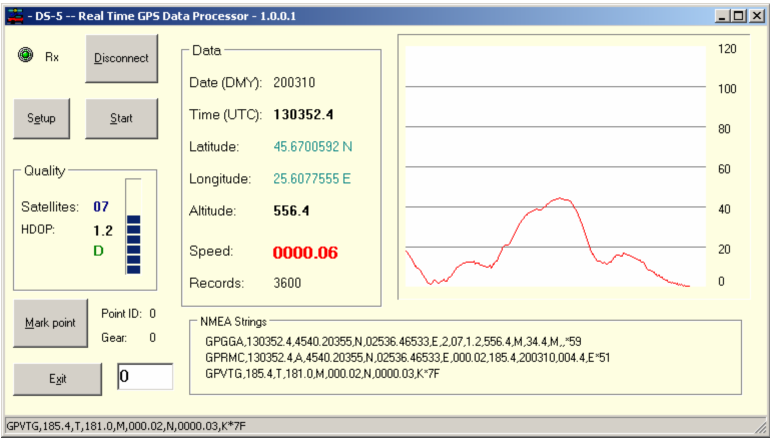

Fig. 4: User interface of the GPS data acquisition software

In order to collect data from the analyzed road, it was used a vehicle equipped with both systems described above. The antennas were both placed on the roof of the vehicle, in a central location (Fig. 5). The systems were powered from an external battery.

The road was traveled four times in both directions. One of the registered tracks is shown in Fig. 6, on Google Earth and also on maping software (recorded data were exported in the standard *gpx* format using the custom CAD application described further in this paper).

Fig. 5: Preparation of the instrumented vehicle

Fig. 6: Visualisation of the track using specialized software

The reception condition in this area is not very good, since the road is bordered by hills and forrests. Even so, the number of satellites received was 5 to 6 with VBox and 7 to 9 with DS-5.

Data processing

Data recorded on the road (text files) were processed further using a special application developed for AutoCAD; the CAD environment offers the advantage of using the functions already developed for processing geometry, so that the new application can be focused on data processing. The interface of a CAD software is much flexible than the interfaces of the software dedicated to mathematic calculation.

The recorded tracks were imported and represented in AutoCAD as shown in Fig. 7.

In this picture are represented all the tracks, for both acquisition systems. The track is composed by points and lines, as geometric entities.

Each point of a track is a line in the source file. In order to draw the track in AutoCAD, the geographic coordinates recorded from the GPS receiver should be converted into cartesian coordinates (from WGS84 Datum to the local projection system, which in Romania is Stereo 70).

Beside the data already stored for a regular entity in AutoCAD, the custom application can attach additional information (metadata) like the geographic coordinates, time, altitude, speed and acceleration.

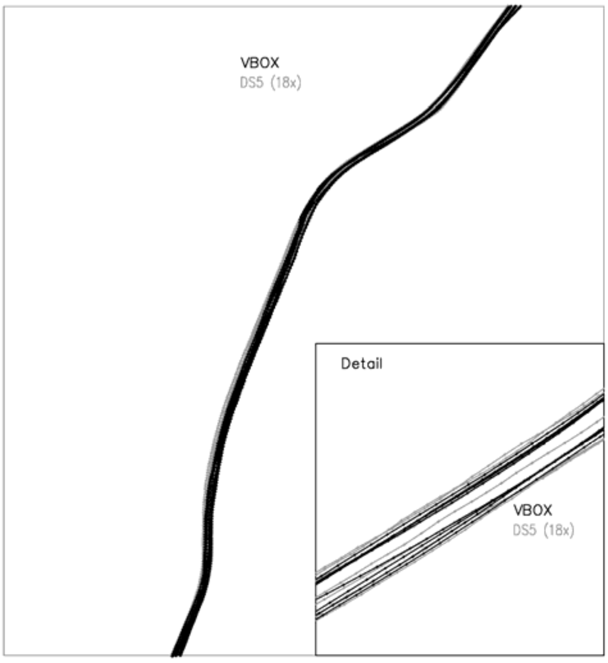

Fig. 7: Tracks represented in AutoCAD

Examples of attached data for *POINT* and *LINE* entities, reported by AutoCAD (*rent* is a custom command used to extract metadata from a selected entity) are below:

```
Command: rent
Select object: (("vxk" . 44.31) ("type" . "gps_point") ("Time" "03" "20"
"2010" "12:57:28.4") ("Long" . 25.6258) ("line2" . "8830") ("line1" .
"881B") ("Lat" . 45.6509) ("id_traseu" . "1") ("id_point" . 1579) ("Alt" .
587.6) ("accx" . 0.0972222))
Command:
Command: rent
Select object: (("speed" . 46.4037) ("type" . "gps_line") ("TimeSec" . 0.2)
("p2" . "8811") ("p1" . "87FC") ("id_traseu" . "1"))
Command:
```

Data associated to a track can be exported in *gpx* or *txt* format, to be processed by other programs. In the *gpx* files are saved the point geographic coordinates (latitude, longitude). The *gpx* files can be loaded in mapping software (like *MapSource*), GIS software or *Google Earth*. The text files (*.txt*) contain location information and dynamic data: velocity, time, acceleration and also some values determined analytical, like the force on wheel. These data can be loaded in spreadsheet programs (*Excel*) or similar.

From the data attached to two points located approximately in the same cross section of a road, it can be noticed that the lateral declivity of the road cannot be ascertained with a satisfactory accuracy.

Example:

```
Command: rent
Select object: (("vxk" . 47.09) ("type" . "gps_point") ("Time" "09" "17"
"2012" "12:32:05.2") ("Long" . 25.5811) ("line2" . "5F75") ("line1" .
"5F60") ("Lat" . 45.5333) ("id_traseu" . "3") ("id_point" . 118) ("Alt" .
837.2) ("accx" . 1.51389))
Command:
```

```
Command:  rent
Select object: (("vxk" . 61.81) ("type" . "gps_point") ("Time" "09" "17"
"2012" "12:34:00.6") ("Long" . 25.5811) ("line2" . "8B25") ("line1" .
"8B10") ("Lat" . 45.5333) ("id_traseu" . "4") ("id_point" . 261) ("Alt" .
839.7) ("accx" . -1.80556))
```

The difference between altitudes shown above is about 2.5 meters, for a distance bethween the two points of about 4.5 meters. This is not possible, and it is obvious that the altitude values recorded non-continuously (at an interval of about 2 minutes in the example above) cannot be used.

Since the goal of this study is to determine the gradient of the road, it was developed a special software routine for representing the altitude as function of the traveled distance. The diagrams for all the eight tracks (registered with both VBox and DS-5 devices) are shown in Fig. 8.

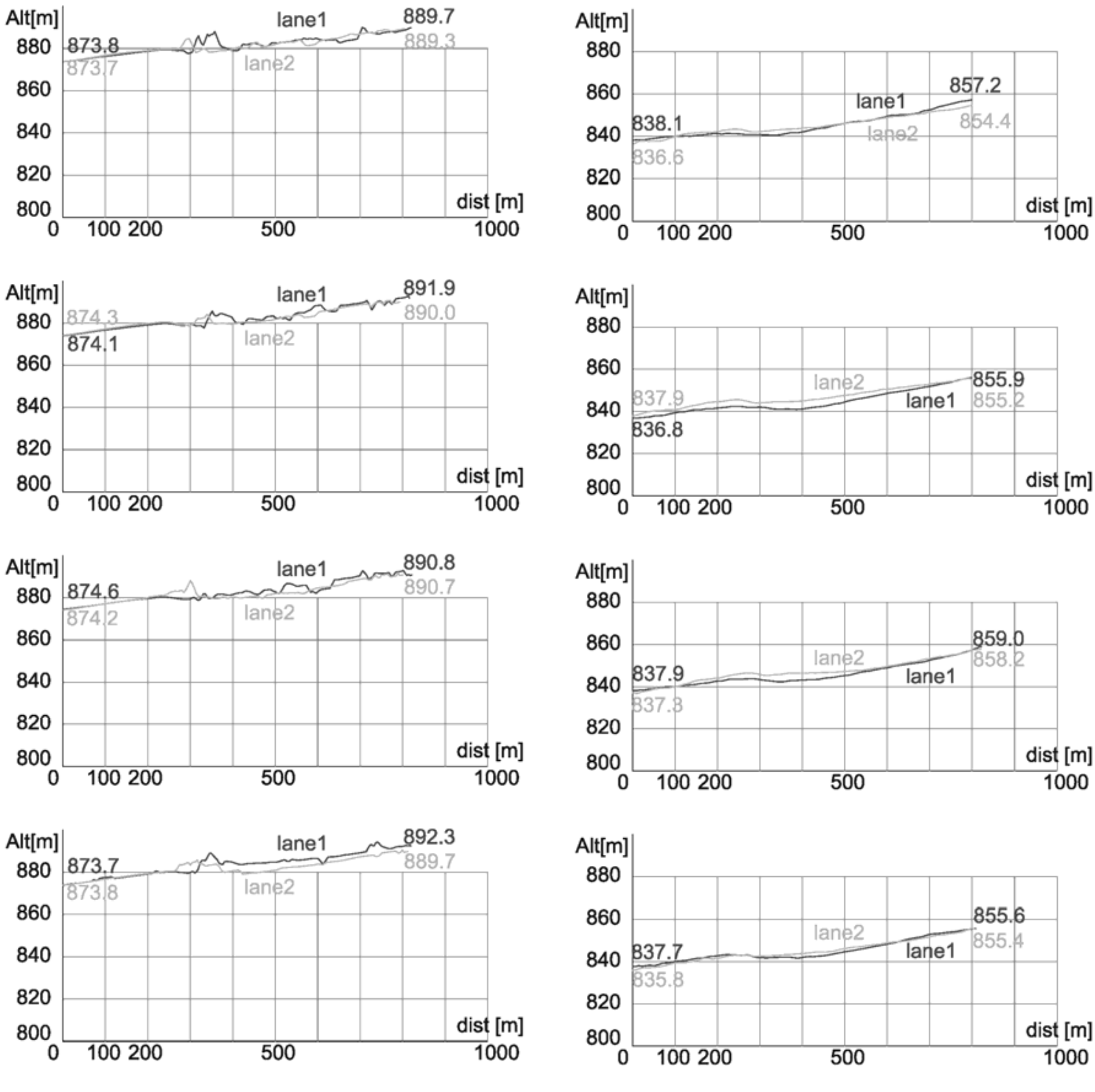

Fig. 8: Altitude versus distance: measurements with Vbox (left) and DS-5 (right)

It can be observed that the altitude values measured with Vbox are higher than those measured with DS-5. Both systems used the WGS84 datum, so the difference may be the result of the different number of visible satellites. From the existing road project we found that the altitude of the road in this area is between 831 and 854 meters. The values measured with DS-5 are close to the real values. On the other hand, it is known that the altitude reported by a GPS receiver is a relative value that depends by the reference geoid used. So the absolute values of the altitude are not as important as the relative values between minimum and maximum. The diagrams in the left column (VBox records) have also some rough variations which affect the results.

The results obtained after completed the data processing are shown in the table below.

Table 1: Average road gradient

GPS 18x-5Hz		Distance 2D	Distance 3D	Road Gradient (deg.)	Road Gradient %
Track 1	up	801	802	1.36	2.4
	down	800	801	1.30	2.3
Track 2	up	799	800	1.38	2.4
	down	797	797	1.24	2.2
Track 3	up	822	823	1.47	2.6
	down	821	822	1.46	2.6
Track 4	up	809	810	1.27	2.2
	down	807	807	1.39	2.4
Average		**807.00**	**807.75**	**1.36**	**2.39**

VBOX III		Distance 2D	Distance 3D	Road Gradient (deg.)	Road Gradient %
Track 1	up	794	822	1.16	2.0
	down	797	805	1.13	2.0
Track 2	up	790	819	1.17	2.0
	down	785	795	1.15	2.0
Track 3	up	795	823	1.18	2.1
	down	790	803	1.21	2.1
Track 4	up	803	821	1.25	2.2
	down	801	814	1.14	2.0
Average		**794.38**	**812.75**	**1.17**	**2.05**

The average values calculated for the road gradient using the VBox measurements are 1.17 degrees and 2.05%. Based on the measurements made with DS-5, the average values are 1.36 degrees and 2.39%. The road gradient obtained with the data taken from the available project (altitudes and distances) is 1.37 degrees and 2.394%, respectively. These results led us to the conclusion that the measurements made with the DS-5 system are accurate enough to establish the longitudinal gradient of a traveled road.

Conclusions

In this study it was analyzed a road segment for which the project and also a geodetic survey were available. Considering these initial information as reference, the same road segment was traveled with a vehicle equipped with two professional GPS sensors: VBox III and DS-5.

The lateral declivity of the road was not possible to be ascertained based on the recorded GPS data.

Instead, for the longitudinal declivity there were obtained accurate results in case of DS-5 system (equipped with the sensor 18x-5Hz from Garmin). The average value for the road gradient, calculated from four passings uphill and downhill, are very similar with the values obtained from the reference project. The results are summarized in Table 2.

Table 2 – Summary of results

	Reference	Vbox	GPS 18x
Slope (deg.)	1.37	1.17	1.36
Deviation (%) (of the slope resistance)	0	14.6	0.75

The main conclusion is that traveling on the road segment with a vehicle instrumented with a system based on GPS 18x sensor it is possible to asctertain the gradient of that road segment with an accuracy good enough for accident reconstruction or similar applications.

References

1. Covaciu, D.; *Use of GPS and CAD in Vehicle Dynamics Study*; VDM Verlag, Saarbruecken, ISBN: 978-3-639-35589-5, 2011.
2. Covaciu, D.; Preda, I.; Ciolan, Gh.; Câmpian, O.V.; *Data acquisition system based on GPS technology, for vehicle dynamics analysis,* The XI-th International Congress on Automotive and Transport Engineering CONAT 2010, Volume 5, paper 4006, pp.31–36, Brasov, Transilvania University, 2010.
3. Ispas, N; Şoica, A; Dima, D; *Proposal of New Versatile Devices for Uses in Traffic Accident Reconstruction*, International Congress on Automotive and Transport Engineering CONAT2010, Brasov, Transilvania University, 2010.
4. ***; *GPS 18x Technical Specifications, Rev.B*, Jan. 2008, Garmin International, http://www.garmin.com
5. ***; *VBOX Tools Software Manual*, Version 1.4, Racelogic, http://www.racelogic.co.uk.
6. ***; *PC-Crash User Manual*.