International Society for Photogrammetry and Remote Sensing
Société Internationale de Photogrammétrie et de Télédétection
Internationale Gesellschaft für Photogrammetrie und Fernerkundung

THE INTERNATIONAL ARCHIVES OF THE PHOTOGRAMMETRY, REMOTE SENSING AND SPATIAL INFORMATION SCIENCES
ARCHIVES INTERNATIONALES DE PHOTOGRAMMÉTRIE, DE TÉLÉDÉTECTION ET DE SCIENCES DE L'INFORMATION SPATIALE
INTERNATIONALES ARCHIV FÜR PHOTOGRAMMETRIE, FERNERKUNDUNG UND RAUMBEZOGENE INFORMATIONSWISSENSCHAFTEN

VOLUME / VOLUME / BAND XXXVI

PART / TOME / TEIL 5 / C55

Proceedings of the 5th Symposium on Mobile Mapping Technology

Padua, Italy
28 – 31 May 2007

Editors
N. El-Sheimy, A. Vettore

Organisers
University of Padua
CIRGEO – Interdepartmental Research Center of Geomatics

Sponsors
University of Padua
CIRGEO – Interdepartmental Research Center of Geomatics

ISSN 1682-1777

Papers were accepted on the basis of peer-reviewed full manuscripts

Integration of An IMU and GPS to Obtain the Exterior Orientation Parameters of Moving Stereo Cameras
Foy Stephen, Mcloughlin Simon, Deegan Catherine ; Mulvihill Ciara ; Fitzgerald Conor ; Markham Charles 106

Intelligent Tuning of a Kalman Filter Using Lowcost Mems Inertial Sensors
Goodall Chris, El-sheimy Naser 112

A Performance Evaluation of Sparse Networks of Continuously Operating Reference Station Networks for Mobile Mapping Applications
Gordini Cristian 120

GNSS Network Real Time Positioning: Testing Procedure to Evaluate the Accuracy of a Geodetic Moving Antenna
Gordini Cristian, Abbondanza Claudio, Barbarella Maurizio 128

Quality Management In Kinematic Laser Scanning Applications
Graefe Gunnar 137

Design and Calibration of a Neural Network-based Adaptive Knowledge System for Multi-sensor Personal Navigation
Grejner-brzezinska Dorota, Charles Toth, Shahram Moafipoor Jay Kwon 143

Use of Mobile Mapping Technology for Post-disaster Damage Information Collection and Integration with Remote Sensing Imagery
Gusella Luca, Adams Beverly J., Bitelli Gabriele 150

Hypothesis Generation of INStances of Road Signs In Color Imagery Captured by Mobile Mapping Systems
Habib Ayman, Jha Maya 159

Lidar System Self-calibration Using Planar Patches from Photogrammetric Data
Habib Ayman, K. Bang, S. Shin Edson Mitishita 166

A 3D Mobile Mapping and Navigation System: Automatic 3D Topological Data Extraction, Network Analyses, Simulation and Interactive Human Visualization
Karas Ismail Rakip, Batuk Fatmagul, Emem Ozan 174

Influence of Tie Point Distribution On Integrated Sensor Orientation
Khoshelham Kourosh, Saadatseresht Mohammad, Rajabi Mohammad Ali 179

An Integrated Mobile Mapping System for Data Acquisition and Automated Asset Extraction
Kingston Tara, Laflamme Claude, Gikas Vassilis Larouche C. 185

Open Source Mobile GIS Solutions for Different Application Fields
Magni Diego, Brovelli Maria A. 190

Compact Airborne Image Mapping System (CAIMS)
Mccarthy Timothy, Fortheringham Asf, O'rian Gearoid 198

Integration of Lidar and Stereoscopic Imagery for Automated Route Corridor Inventory
Mccarthy Timothy, Charlton Martin, Fortheringham Asf O'malley Vincent 203

Relational Strategies In Statistical Data Analysis: Mapping, Inferences, Clustering, Topologies, Matching
Mussio Luigi, Dante Valentina 210

Mapping of Object Awareness Using Mobile Vision Services
Paletta Lucas, Seifert Christin, Benesova Wanda Andreu Jean-philippe 217

A Mobile System for Vision Based Road Sign Inventory
Paletta Lucas, Fritz Gerald, Wanda Benesova Yuriy Lypetskyy Jean Philippe Andreu Andrea Jeitler Evelyn Hodl 225

Accuracy Check of Road's Cross Slope Evaluation Using MMS Vehicle
Piemonte Andrea, Caroti Gabriella, Bolzon Giorgio 230

ACCURACY CHECK OF ROAD'S CROSS SLOPE EVALUATION USING MMS VEHICLE

G. Bolzon [a], G. Caroti [b], A. Piemonte [b]

[a] Centro di Eccellenza per la Ricerca in Telegeomatica – Università degli Studi di Trieste – bolzon@dsm.units.it
[b] Sede di Topografia e Fotogrammetria – Dipartimento di Ingegneria Civile – Università di Pisa – caroti@ing.unipi.it

KEY WORDS: Road's cadastre, cross slope, MMS

ABSTRACT:

Department of Civil Engineering (DCE), seat of Topography and Photogrammetry – Pisa University, cooperating with Excellence Centre for Telegeomatics Research of the Trieste University, is developing several methods in order to evaluate road's cross slope. This measure is performed by use of instrumentation integrated on MMS vehicle GIGI One. In particular two different approaches are followed. The first one preview using of low cost monoaxial laser scanner IBEO Automotive LD GmbH, synchronized with Applanix POS LV system. With the second one cross slope is calculated by only inertial system data, using a simplified algorithm that describes vehicle dynamics.
This paper will present an accuracy control of both methods. This control is realised on two different datasets, relating to the s.s. 58 Strada Nuova per Opicina, joining Trieste to Opicina and the s.s.1 Aurelia between Rosignano and Campolecciano, near Livorno.
The control compares the two method's results systematically and preview several single point check by tests realised with classic topographic instrumentation.

1. INTRODUCTION

Mobile Mapping Systems (MMS) equipped with Inertial Navigation Systems (INS) coupled with Differential Global Positioning System (DGPS) have become quite popular in a variety of applications including the highway evaluation operations.
The roadway geometric data typically obtained by the MMS are cross-slopes, grades of vertical curves and radii of curvature of horizontal curves. In this paper only cross-slope measure is analysed.
The function of the cross-slope provided in a roadway is to accelerate the drainage of rain water and reduce the hydroplaning potential. The typical cross-slope requirement of a roadway is 2%. In addition, roads are sloped in the lateral direction to control the lateral wandering of vehicles travelling on a bend by meeting the centripetal force requirement of the vehicle. This construction feature is commonly known as the super-elevation at the curve and is provided in the direction of the curve in all of the lane.
MMS used for these tests is GIGI One, in charge of Centre for Telegeomatics Research of the Trieste University. This vehicle is equipped with an Applanix POS LV INS/DGPS system and a low cost monoaxial laser scanner IBEO Automotive LD GmbH. Applanix output raw data are following: vehicle's reference point X, Y, Z in WGS84 coordinates, roll, pitch and yaw angles of tilts, heading and acceleration components with respect to the body coordinate system. All these values can be recorded at a frequency of 200Hz.
There are several algorithms that calculate grades and radii of curvature from axis points coordinates but with only axis coordinates it is not possible to calculate a cross slope value.
In order to obtain a cross-slope value it is possible to perform a synchronised laser scanner survey or calculate it through an algorithm developed by writers, using Inertial Measuring Unit (IMU) values only of angles of tilts and accelerations.
The tests described on this paper are aimed to verify accuracy and precision of measures resulting from this algorithm.

2. SURVEY METHODS AND ALGORITHMS

Cross slope values can be obtained, by processing data collected by the MMS GIGI One vehicle, in accordance with two different methods, the first of which implements an algorithm which computes the slope value just by means of the data collected by the inertial system, on the basis of a simplified model of the dynamics of the travelling vehicle, while the second implements a single axis laser scanner synchronised with the INS/DGPS system.

2.1 Cross slope obtained from INS data only

The vehicle is represented as a rigid body, bound, rather than rigidly constrained, to a horizontal constraint plane by means of two springs, which simulate respectively the right- and left-hand wheel-suspension pair.
It is assumed that the suspensions have a linear elastic behaviour: it is a two-dimensional (mass-springs) system, in which the mass is a rigid body subject to rotation.
With the model lying on an inclined plane and subject to gravity and to a transversal force, it simulates a vehicle going along a curvilinear road section with a cross slope α (Figure 1).

The variables involved are:

- a transversal acceleration value;
- m mass of the vehicle;
- G mass centre of the vehicle;
- l height of G above the plane;
- d shift of G in relation to the vehicle's axis;
- g gravity acceleration.

The stresses are computed on the non-deformed configuration according to the usual procedures in mechanical sciences.

Forces acting parallel to the inclined plane are the gravity component, g·sinα, and the transversal acceleration a, provided by the IMU. Hence, the moment due to lateral force is:

$$M_L = ml\,(a - g\sin\alpha) \qquad [1]$$

If the load is eccentric, (d ≠ 0), there is a moment due to gravity: the trim of the vehicle depends on the eccentricity, or asymmetry, of the load, and is assumed to remain constant throughout the entire survey. Hence, the moment due to the trim of the vehicle is:

$$M_a = md\,g\cos\alpha \qquad [2]$$

The resulting tilt moment on the vehicle is:

$$M = M_L + M_a \qquad [3]$$

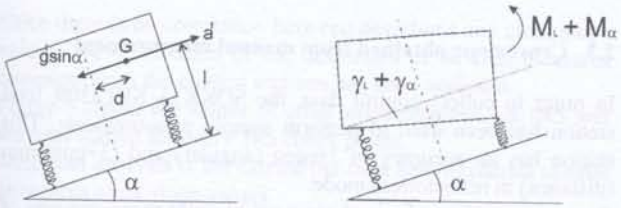

Figure 1: non-deformed and deformed configurations on inclined plane.

which yields the tilt of the vehicle compared with the non-deformed configuration:

$$\begin{aligned}\gamma &= -2\frac{M}{k_s h^2} \\ &= -2\frac{ml(a - g\sin\alpha)}{k_s h^2} - 2\frac{mdg\cos\alpha}{k_s h^2} \\ &= \gamma_L + \gamma_a\end{aligned} \qquad [4]$$

Assuming small angles (cosα ≈ 1), the value of γ_a is constant. The constant

$$K = \frac{2ml}{k_s h^2} \qquad [5]$$

which incorporates the mechanical and geometrical characteristics of the vehicle, is defined for convenience purposes. Hence, the angle of vehicle floor with respect of road's pavement is:

$$\gamma = -K(a - g\sin\alpha) + \gamma_a \qquad [6]$$

The roll angle of the vehicle is comprised between the reference plane of the vehicle and the horizontal one. Therefore, the relation

$$roll = \alpha + \gamma \qquad [7]$$

is in force, which, substituting γ, provides the general equation relating α, γ and roll:

$$\alpha - Ka + Kg\sin\alpha + \gamma_a = roll \qquad [8]$$

Assuming small angle values, (sinα ≈ α), we have:

$$\alpha = \frac{Ka + roll - \gamma_a}{1 + Kg} \qquad [9]$$

Hence, the cross slope of the road is related to transversal acceleration and roll values, as well as to the K and γ_a parameters, which depend upon the specific vehicle and can also change, for the same vehicle from one survey to another.
It is not excluded that these parameters are subject to variability in relation to environmental conditions, such as temperature and humidity. Besides, constant Ks incorporates the behaviour not only of the suspensions, but also of the tyres, whose pressure varies in relation with temperature as well as with their maintenance conditions.
Anyway, it is assumed, for simplifying purposes, that the geometrical and elastic characteristics of the vehicle do not change throughout each survey.
For this reason, it is necessary to fix the current values of these parameters prior to surveying. These operations are known as model calibration, and can be carried out according to two procedures, depending on the availability of a laser scanner synchronised with the IMU.
If none scanner is available, K and γ_a are fixed by covering circular paths and repeatedly passing over the same spot, which can conveniently be shown on the ground.
Applying equation [8] at this spot

$$\alpha - Ka + Kg\sin\alpha + \gamma_a = roll \qquad [10]$$

we have that α, although unknown, is a constant: hence, the *roll* value is linearly related to the lateral acceleration. Constant K can be obtained from the set of the pairs (*a, roll*). The indetermination of α, however, doesn't allow to fix the trim angle γ_a: for this reason, the survey must be carried out on at least one spot with known cross slope.

2.2 Cross slope obtained from INS/DGPS – laser scanner integrated data

The IBEO LD Automotive laser sensor (figure 2) is a class 1, rotating laser distance meter, running on 12V DC power supply, with ARCnet and CAN interfaces for data transmission, plus

one RS-232 interface for firmware updates. Its range is about 40m for surfaces with reflectivity ≥ 5% and about 250m with reflectors, while its stated precision is 5cm and the reading field 360°. This instrument is aimed at vehicle appliances, in particular fixed or moving obstacles detection.
The distance meter has been overhung on the rear end of the MMS GIGI One vehicle, in order to survey the cross section of the road.

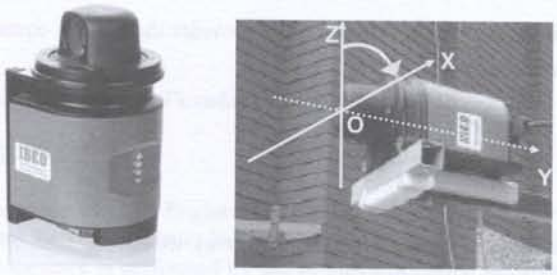

Figure 2: IBEO LD Automotive laser sensor.

In this particular case, the vehicle's position and trim at each scan time can be obtained via an independent circuit, generating a pulse of adequate amplitude at even intervals, which, after having been triggered via software from the scan start, travels to a DIO (Digital Input Output) port on the Applanix positioning system, which records the scan time.
It is assumed as right to consider the points of the section obtained by the laser scan as orthogonal to the road axis, since the X axis of the local reference system roughly corresponds with this direction. With these conditions, the mask to be applied to the X coordinates of the point cloud, in order to filter just the points belonging to the roadway, is the following:

$$-\frac{D}{2}-d < X < \frac{D}{2} \qquad [11]$$

where D is the roadway width and d is the distance between the centre of the local reference system and the road axis (figure 3).

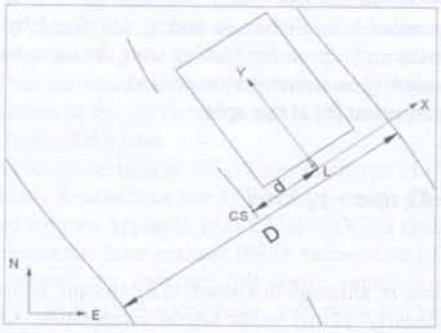

Figure 3: Position of MMS and laser on the lane.

In addition, a mask is applied also to the Z coordinates, in order to filter out any disturbance due to passing vehicles:

$$-3 < Z < -1.5 \qquad [12]$$

Basis for laser method in estimating the cross slope of the roadway is the least squares approximation of the laser sensor readings using a linear fit. All the laser measurements obtained from the vehicle are specified with respect to the coordinate system originating from the centre of laser system. Therefore, equation [13] is used to convert coordinates from laser frame to the vertical and horizontal (x,z) coordinate system. Roll angle value from INS is used in this formula.

$$\begin{pmatrix} x \\ z \end{pmatrix} = \begin{pmatrix} \cos(roll) & \sin(roll) \\ -\sin(roll) & \cos(roll) \end{pmatrix} \cdot \begin{pmatrix} x_i \\ z_i \end{pmatrix} \qquad [13]$$

The resulting point dispersion is divided in the two dispersions, representing the two halves of the roadway; the cross slope is computed by means of the angular coefficient of the linear regression straight line:

$$\alpha = tg^{-1}\left(\frac{n \cdot \sum_{i=1}^{n} x_i \cdot z_i - \sum_{i=1}^{n} x_i \cdot \sum_{i=1}^{n} z_i}{n \cdot \sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i \right)^2} \right) \qquad [14]$$

2.3 Cross slope obtained from manual measurement

In order to collect control data, the SOKKIA SET330R total station has been used to perform sample measurements. This station has an accuracy of 1mgon (angular) and (3+ppm)mm (distance) in reflectorless mode.
Cross slope values obtained via a set of point measurements of the road section have a greater precision than the other proposed methods, and can be regarded to, for the purposes of the present work, as true values.

3. EXPERIMENTAL RESULTS

The experimental data shown in the present work have been collected during two survey sessions.
The first one has been performed in July, 2006, on SS 1 (Aurelia) between Rosignano and Campolecciano, near Livorno, for a total of 12km.
The second survey has been performed in February, 2007, on SS 58 (Strada nuova per Opicina), near Trieste, for a total of 7km.
SS 1 has been surveyed by MMS (one passage in each direction) and by total station (17 control sections).
SS 58 has been surveyed by MMS, with INS and laser scanning data (three passages in each direction) and by total station (21 control sections).

3.1 Cross slope values and deviations correlation

The precision of measurements obtained via the developed algorithm has been initially checked for any relation to the value of the measured angle.
For this purpose, the deviations between INS measures and the 'true' reference value, obtained via total station, have been determined.
Figure 4 charts the dispersion of these deviation for 145 available measures.

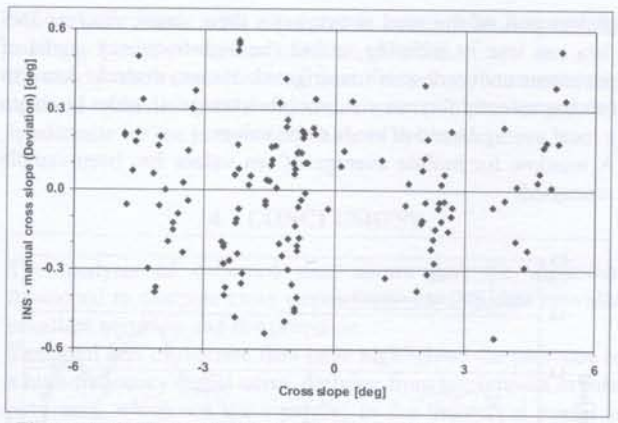

Figure 4. Scatter plot of cross slopes and INS - manual cross slope value deviations

Correlation between deviations and values is, in effect, null for a sample of fair significance. It can be therefore assumed that the algorithm allows for cross slope determination and its precision is independent from the slope itself and from the path covered by the surveying vehicle.

3.2 Comparison between manual and INS measure

Since there is no correlation between deviations and cross slope values, the distribution of the deviations of all INS measures compared with the control sections has been analysed.
Figure 5 charts the values of cross slope obtained via INS and via total station for every 145 check points.
Statistical analysis is the carried out on a heterogeneous sample as regards cross slope values.

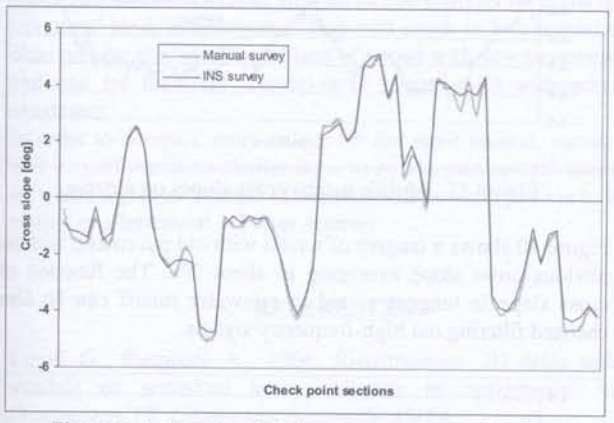

Figure 5. Manual and INS measures on check points

The distribution of measure deviations (figure 6) has a standard deviation of 0.26° and a mean of +0.03°. Hence, it can be assumed that the algorithm is not affected by systematic errors and allows for a fair precision in cross slope determination.
Spot control sections belong both to roads with old pavement both to roads with new pavement.
If we consider for statistical analysis only survey sections on new pavement roadway, better results are obtained.
This subset distribution of measure deviations has a standard deviation of 0.18° and a null mean, but only 50 measure available.

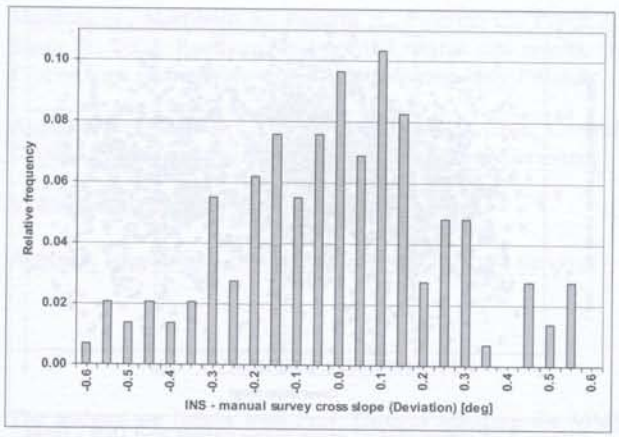

Figure 6. Deviations frequencies distribution

3.3 Comparison between laser and INS measure

Due to higher resource consumption, the amount of control sections surveyed via total station, although relevant, is not comparable to that of INS determination, which can be carried out at the same rate of the INS/DGPS system, i.e. up to 200Hz. The SS 58 survey includes a cross slope determination every 1m, for a total of 41088 measures, as well as data collected via the IBEO laser scanner. In the three passages of the 7km long paths in both directions, 5300 cross slope determinations have been obtained from laser scanning.
Values obtained via these technologies have therefore been systematically compared, excluding laser determinations referring to the opposite lane, which show high noise levels due to passing cars. The comparison is the performed on 2650 laser measures and three sets of 2650 INS measures each, corresponding to the same distance, for a total of 7950 samples.

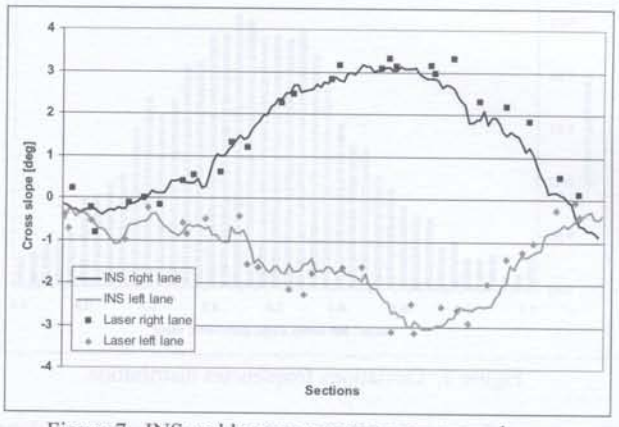

Figure 7. INS and laser measures on an example curve

Figure 7 shows the comparison between these two kinds of determination in the SS 58 section between km 0+460 and km 0+600.
Values obtained via laser scanning have been chosen as reference, to check for the absence of any correlation between cross slope value and differences between laser and INS measures.
As point dispersion in figure 8 shows, no such correlation can be detected, and it can be again assumed that measurement precision is not dependent from the value itself.

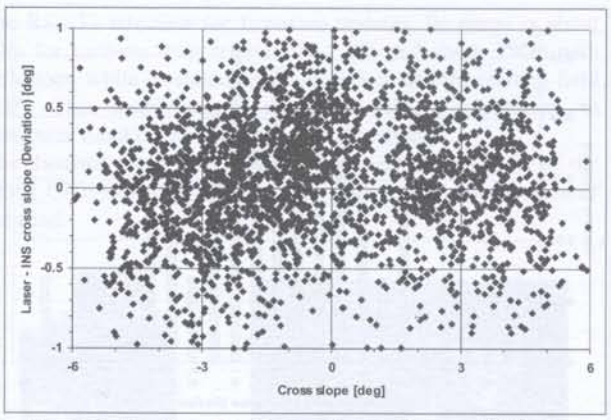

Figure 8. Scatter plot of cross slope values and INS - laser measures deviations

The distribution of the deviations for the 7950 samples (Figure 9) shows a standard deviation of 0.38° and a mean of +0.07°. This parameter, in the comparison between INS and total station measurements, amounted to 0.03°, and was small enough to assume that no systematic errors had occurred.
Comparison of laser vs. INS measures yields yet again a positive differences mean value, greater than the total station vs. INS one.
This result indeed highlights a problem related to cross slope measure. Lanes are not usually planar surfaces, and their section is represented by a curve, rather than by a segment of straight line. Both laser and total station measures refer to several points lying on the section, and the measured cross slope equals that of the straight line interpolating those points.

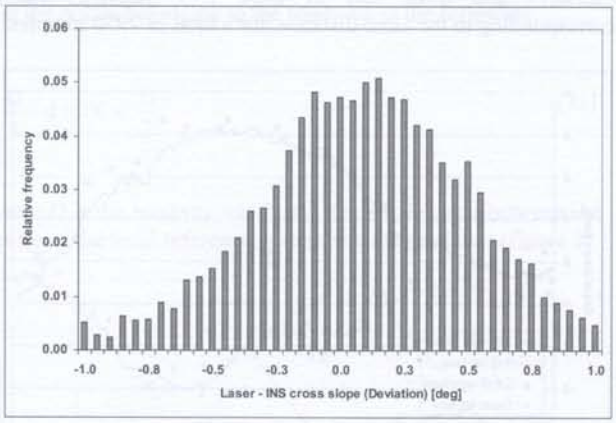

Figure 9. Deviations frequencies distribution

Surveys performed via MMS, on the contrary, yield the slope related to the contact points between the wheels of the vehicle itself and the road.
Assuming that the MMS path is centred on the lane, values obtained via the different methods show little variations along with, as in this case, a mean of the deviations slightly differing from zero.
Data collected in the SS 58 survey show that the difference is greater in road sections with old pavement and smaller in road sections with new pavement.

3.4 Use of filtered data

Comments in the above paragraph show a certain noise level in MMS measures, due to unevenness in road pavement, which is greater in sections with old pavement, which represent the greater part of the road network. In these cases, discrete INS data can lose its meaning, unless the high-frequency signal of pavement unevenness is investigated. Hence, discrete data can be conveniently filtered via a mobile average, in order to obtain a local average trend of cross slope values.
A window for mobile average of ten values has been sample processed.

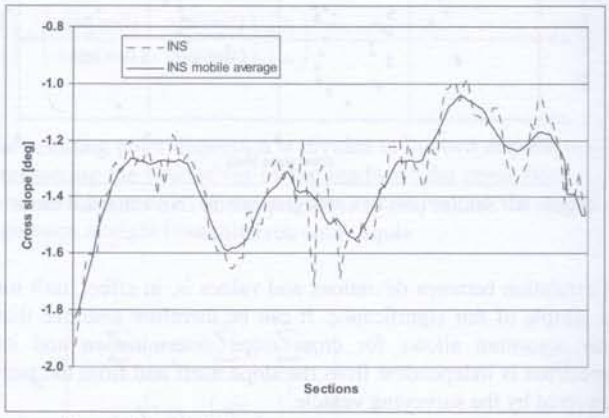

Figure 10. Mobile means cross slopes on a tangent

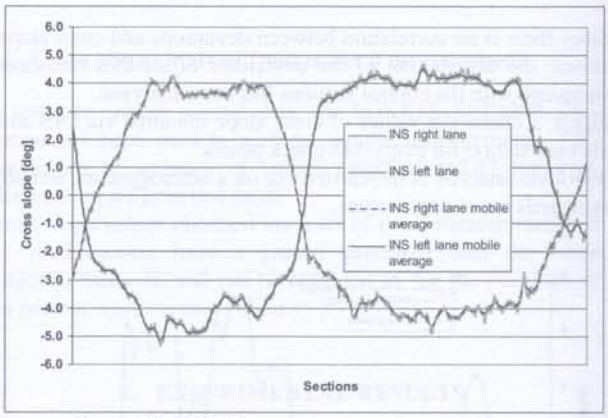

Figure 11. Mobile means cross slopes on a curve

Figure 10 shows a tangent of a road with old pavement, with an obvious cross slope averaging at about 2%. The function of cross slope in tangent as aid to rainwater runoff can be also checked filtering out high-frequency signals.

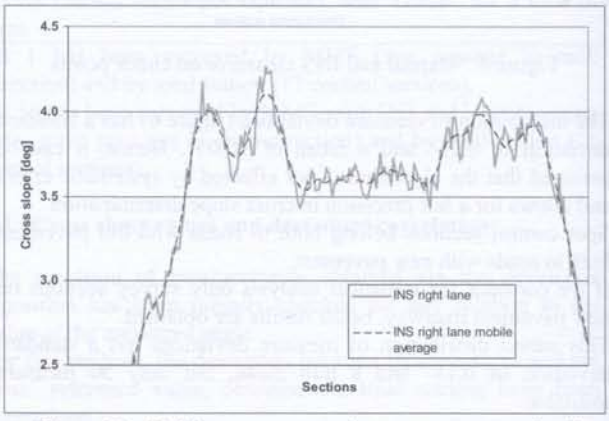

Figure 12. Mobile means cross slopes on a curve - detail

Figure 11 shows a series of two bends, one to the right and one to the left. The filtered data shows clearly the transition

between the bends with a tangent in which both lanes of the roadway have a cross slope of about –1° (2%).
Figure 12 shows a subset of data from the above example, referred to the left-hand lane; in this case too the averaged data is adequate for the geometrical study of the bend.

4. CONCLUSIONS

The analysis of collected data shows that the algorithm developed to compute cross slopes from just INS data provides excellent accuracy and fair precision.
Temporal sets of discrete data have highlighted the presence of a high-frequency signal noise, deriving from unevenness in road pavement, which, on the contrary, in the theoretical model is represented as an ideal planar surface, inclined by the cross slope itself.
Besides, discrete comparison can not ensure that the section under investigation is actually the same in all of the methods used – total station, laser scanning and INS. Sections could be shifted by up to tens of centimetres, due to the precision in georeferencing the sections themselves.
It is also obvious (see paragraph 3.2) that surveys performed on roads with new pavement differ from those carried out on roads with old pavement; in the first case, the road surface is more even, measures show less noise and values obtained via INS can be more easily compared to those obtained via total station.
Data collected along roads with old pavement are affected by noise, due to the unevenness of the surface, which can result in problem in the correct determination – even just theoretically – of the cross slope, apart from comparison towards other surveying methods.
To improve precision analysis for the INS method new test are under development, first of all with ad hoc analysis for different pavement kinds maintenance. This will result in two precision data: one for the 'ideal' condition of a road with new pavement, and one for the 'real' condition of a road with widespread roughness.
In order to compare more values for the same section, surveys will be performed on shorter legs, to be covered several times, on which a greater amount of sections will be surveyed via total station or a terrestrial 3D laser scanner.

5. REFERENCES

Caroti G., Piemonte A., 2006. Ricostruzione 3D della sede stradale da scansioni laser realizzate in movimento. In: *Proceedings 10ª Conferenza Nazionale ASITA.*

Gunaratne M., Mraz A., Randeniya D., 2006 Evaluation and Validation of a High-Speed Multi-Function System for Automated Pavement Condition Survey. *Final Report.* Department of Civil and Environmental Engineering-University of South Florida

Bolzon G., Piemonte A., 2005. Stima delle pendenze trasversali della strada tramite misure IMU a fini catastali. In: *Proceedings 50° Convegno SIFET.*

Pagurut R., 2005. Gestione dei sensori di un MMS terrestre. PHD Thesis, XVII ciclo del dottorato in Geomatica e Sistemi Informativi Territoriali, Università degli Studi di Trieste.

Manzoni G., Martinolli S., Pagurut R., Palermo C., Purga A., Sluga T., 2003. Road survey by GIGI: status and results. In: *Proceedings of the Bilateral Geodetic Meeting Italy-Poland,*

Applanix corporation, 2003, *POS LV GIE User Control, Display, Data and Logging Port Interface Control Document.*

V.Willhoeft, 2002, *LD Automotive User Manual.*

Applanix corporation, 2000, *Redefining the way you survey.*

6. ACKNOWLEDGEMENTS

The authors are indebt with Prof. Giorgio Manzoni for MMS GIGI One availability.
Collaboration on survey step of Dr. Shaula Martinolli (technician of CER Telegeomatics Trieste) and Dr. Andrea Bedini and Geom. Jessica Micheloni (technicians of DIC Pisa) is gratefully acknowledged.