A COST-EFFECTIVE ROAD SURVEYING METHOD FOR THE ASSESSMENT OF ROAD ALIGNMENTS

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1. INTRODUCTION

Roads have been, since the introduction of motor vehicles, one of the basic pillars of a modern society. Today almost 1 out of every 2 inhabitants in the 15 EU-Countries is an owner of a passenger car with increasing trend. But besides people, goods are reaching the consumer mostly via the road network (35% increase in the last decade within the EU). Keeping up with such a demanding system is vital for the whole EU.

Preserving the operability of the road network is a basic concern of modern societies. Another equally important concern is road safety. Increased car ownership and increased traveled vehicle-kilometers have raised the accident numbers within Europe and the whole world. Roads of Europe claimed nearly 43.000 lives in 1998. Worldwide the yearly numbers are 500.000 fatalities and 15.000.000 injuries from which tens of thousands are maimed for life.

Operability and safety of a road network is a major concern to all road agencies especially in EU and N. America. To manage effectively the existing road network all of its design parameters and installed equipment have to be known accurately enough. And while for newly constructed roads there exist sufficient data, there is a considerable lack of data regarding older roads constructed and maintained under various road jurisdictions. A need for road mapping systems exists worldwide, which will provide agencies with the missing road data.

In the following a cost-effective road surveying system will be briefly described. The system was developed at the National Technical University of Athens and has been used up to now to survey about 1.300 km long segments of the national road network of Greece, of which 500 km have been already assessed and concrete measures have been proposed for enhancing both the operability and safety of the specific road length.

2. SYSTEM OPERATIONAL REQUIREMENTS

Effective highway surveying systems must fit the reliability requirements set by highway agencies, which will operate and sustain such a system. A too accurate or a not adequately accurate system has the same effect: too expensive to implement.

An effective road surveying system should provide reliable quantitative road data from which a highway engineer could:

1) Check the compliance of the alignment with the existing design policies.
2) Determine the Level of Service of a specific road segment (vehicle volume capable of passing through a cross-section at a specific speed range).
3) Carry out a safety evaluation of the roadway. This evaluation should at least examine the outcome of the application of the three basic **safety criteria** of a modern roadway:
   (a) achieving **design consistency** (safety criterion I);
   (b) achieving **operating speed consistency** (safety criterion II); and
   (c) achieving **driving dynamic consistency** (safety criterion III) [*Lamm, Psarianos, Mailaender, 1999*].
4) Assess the existing signing and markings.
5) Provide a reference system to support a road data bank for selected roadway features such as appurtenances, skid numbers, etc. which subsequently could be supplied to a corresponding Geographic Information System suitable for transportation purposes (GIS-T).

To fulfill the above requirements the road surveying system should be able to provide road data, which would comply with the accuracy requirements of the preliminary road design. That means that the road data should fit to a map and plan scale of **at least 1:1000**. As a consequence highway engineers should be in position to determine:

(d) The functional category of the road.
(e) The design speed.
(f) The number and widths of all cross-section elements (lanes, medians, edge strips, shoulders).
(g) The design elements of the horizontal alignment (tangents, transition curves and circular arcs) and their physical parameters (radii, etc).
(h) The design elements of the vertical alignment (upgrade and downgrade tangents, crest and sag vertical curves) and their physical parameters (slopes and radii).
(i) The superelevation rates and the superelevation runoff.
(j) The position of various road appurtenances and other traffic influencing devices or equipment.

Provision of the above information is sufficient for the assessment of the operating and safety features of the roadway, since all other necessary critical design features (operating speeds, stopping and passing sight distances, drainage, level of service, signing adequacy etc.) can be readily deducted from the above data set.

3. THE ROAD MAPPING SYSTEM

Taking into account the system requirements mentioned above, the complete road mapping system was designed and materialized in order to cover the determination of the track of the vehicle in space (relative kinematic positioning) and at the same time the recording of the surrounding area of the road (traffic signs, etc.).

The system consists of three main parts:

1. The satellite positioning system (GPS).
2. The inclinometer, for the inclination measurements of the road surface.
3. The video cameras, for the recording of the road and the surrounding area.

Moreover, assisting control, synchronization circuits and computers are used in order to check and control the equipment and record the measurements.

Figure 1 shows a general diagram of the whole measurement system. The GPS receiver and antenna (I) is connected to a PC (I), which records orbits and measurements to all visible satellites. The inclinometer is also connected to the same computer so that inclination readings are recorded at the same time. The GPS receiver and antenna (in one unit) (II) works only in time transfer mode and it controls a synchronization circuit, so that the three cameras record at exactly the same epoch. Although the three cameras record on tapes independently, through a control circuit a composite picture from the three cameras is produced which is shown on the PC screen (II) and also recorded. GPS time is the common time scale for all units and measurements.

The whole system was installed in a mini-van Ford Transit (Fig. 2). The GPS receivers, the video unit, which records the composite picture, the computers, the power system and the control units, were put inside the van. On the rear axis of the vehicle the inclinometer was put, so that it would not be affected by any possible inclination of the body of the car.

On the roof of the car (Fig. 2) a stable platform was installed, which contains the three cameras, the first oriented along the axis of the car, the other two vertical to it, recording to the left and right. Power system, control and synchronization circuits are also there and of course the GPS antennas.

The system was tested extensively before the actual field work with very good results.

The positioning method adopted was the post processed relative kinematic positioning with on the fly ambiguity resolution. The reference and rover receiver measurements were combined in order to determine the track of the vehicle in space with accuracy of the order of 4cm at distances of the rover up to 60km from the reference station.

The optical positioning method involving the analysis of frames taken at the same epoch proved to be accurate to ±1m with respect to the road axis, and the inclination gave an accuracy of 1%.

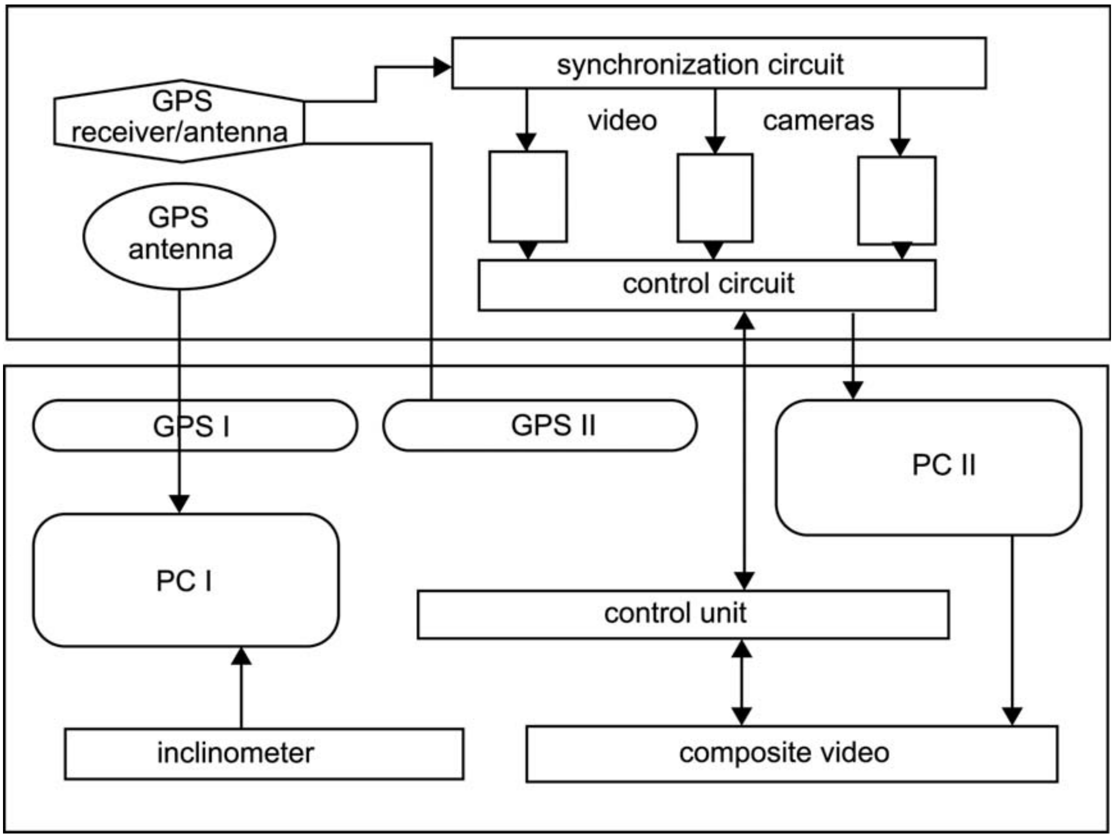

Figure 1: Diagram of the measurement system

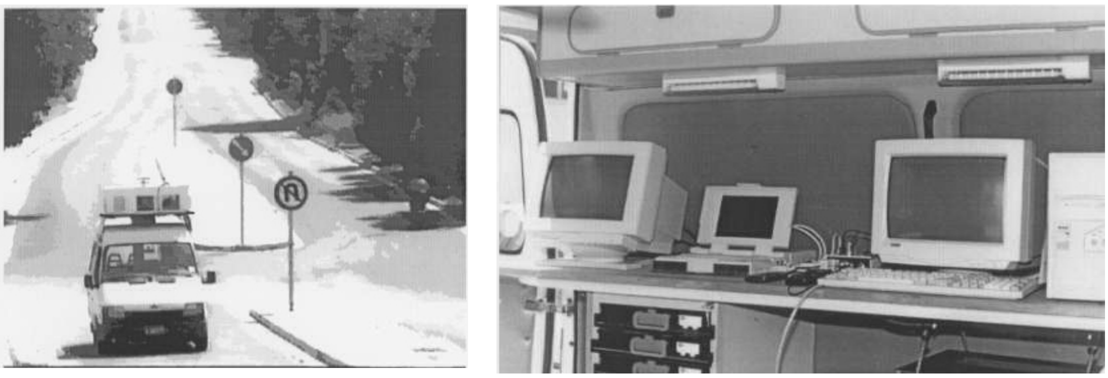

Figure 2: External and internal view of the measuring system

3. MEASUREMENT OF WIDTHS

One of the major measuring problems encountered was the measurement of widths of the various design elements of the cross-section. The problem to a wide extend was addressed by applying photogrammetric monoscopic measurements on the video imageries recorded from the video equipment. The method developed and deployed is relatively simple, cost-effective and very reliable, where applicable. The method is described in the following in the case of measuring lane widths.

The basic geometry of lane width measurement is depicted in Figure 3, in which O denotes the perspective center and M is the image center. The X axis in object space and the x image coordinate axis are normal to the plane of the Figure.

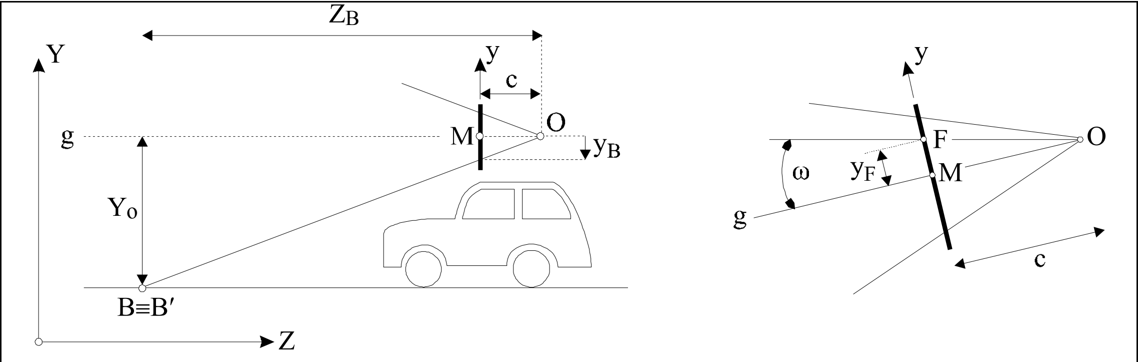

Figure 3. Image acquisition geometry with camera axis horizontal (left) and tilted (right).

On the left, the situation is illustrated when the camera axis is horizontal. The camera constant is denoted by c, while y_B is the y image coordinate of points B and B′ on the road surface defining lane width. If Y_o is the camera height above ground level, then image scale at the distance Z_B is expressed as

$$\frac{c}{Z_B} = -\frac{y_B}{Y_o} = \frac{\Delta x_B}{\Delta X_B} \tag{1}$$

with ΔX_B denoting the lane width BB′ and Δx_B being the corresponding length measured on the image. Unfortunately, this simple geometry cannot be retained during car movement, i.e. small tilts are generally to be expected. However, the effects of small rotations about the camera axis (κ rotation in standard photogrammetric notation) or about the vertical y image axis (φ rotation) may be practically neglected in the case under study. On the contrary, the ω rotation about the horizontal x image axis is important as the projective rays form small angles with the plane of the road. Consequently, even small ω-tilts might cause large errors when not taken into account. The introduction of a small ω-angle into the well-established collinearity equations employed in photogrammetry modifies Eq. 1 as follows for the determination of a lane width ΔX:

$$\frac{\Delta x}{\Delta X} = -\frac{y\cos\omega + c\sin\omega}{Y_o} \approx -\frac{y + c\omega}{Y_o} \tag{2}$$

The simplest way to estimate an ω-tilt is by using the vanishing point of the Z direction of depth, found graphically on the frame. One can define the vanishing point F of a straight road segment by exploiting road delineation on the video frames, as shown in Figure 4.

Figure 4. Graphical determination of vanishing points.

From Figure 3 it may be seen that ω-tilts can be adequately approximated as follows:

$$\tan\omega = -\frac{y_F}{c} \approx \omega \quad \rightarrow \quad c\omega \approx -y_F \tag{3}$$

Introduction of Eq. 3 into Eq. 2 yields:

$$\Delta X = \frac{\Delta x}{-y + y_F} Y_o \tag{4}$$

Finally, if the x and y image measurements are performed directly in pixel dimensions, the final equation becomes, according to Fig. 5:

$$\Delta X = \frac{\Delta x}{y - y_F} Y_o \tag{5}$$

This last Eq. 5 is the formula used here to connect a lane width Δx measured on the image (at a certain y image coordinate) through the vanishing point F of the road direction with the corresponding actual lane width ΔX.

The above approach has certain advantages. For instance, Eq. 5 involves no camera calibration data, which means that uncalibrated videocameras may well be employed.

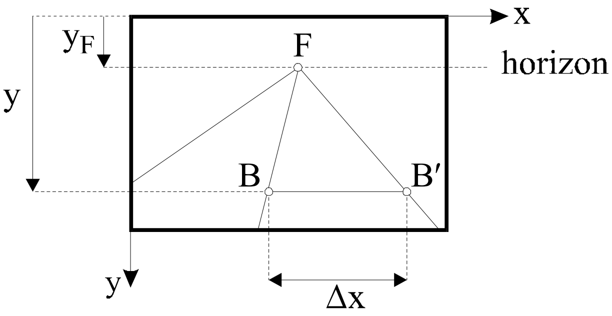

Figure 5. Measurements on the digital image.

Furthermore, the expected affine deformation of the image introduced in the frame-grabbing process is easily handled. Although care had been taken to ensure horizontal camera axis and repeatability of positioning, certain frames were taken at the start of each recording session for calibration purposes. The lane widths ΔX shown on these frames had been measured with a tape and were later used to estimate camera height Y_o from Eq. 5. This value of Y_o does not represent the actual camera height but is affected by image affinity. This value is subsequently used in Eq. 5 together with the x, y image measurements and, hence, correct ΔX results are obtained.

Before employing the described approach on a routine basis, its accuracy was assessed. To this end, 10 frames were first used to estimate a camera height Y_o from known widths (which ranged between 3.5 and 7.5 m). Then, 5 frames were selected for each of 6 different sites. Here, too, the lane widths had been measured by tape to serve for checking purposes. On each of these 30 frames, 5 different Δx measurements were taken at different y levels on the image plane, as illustrated in Figure 6, and corresponding ground lane widths ΔX were computed.

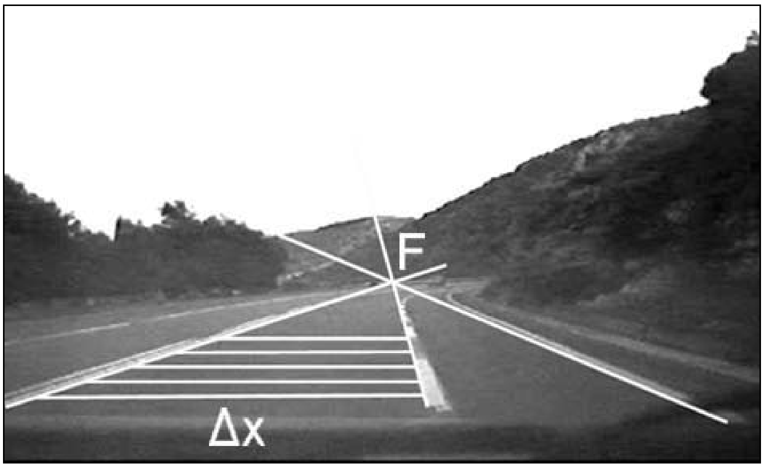

Figure 6. Measurements of lane width Δx at different image heights y.

All five ΔX measurements from each frame were averaged to produce the absolute mean difference (d) from the known ΔX value. The standard deviation (σ) of the five measurements was also found. Finally, their rms difference (s) from the known width were also computed. The resulting mean values from 30 frames were as follows:

Accuracy assessment of lane width measurement from 30 frames (mean values)

difference (d)	standard deviation (σ)	rms difference (s)
2.3 cm	± 3.8 cm	4.7 cm

The above results are considered as satisfactory, since individual measurements of lane width are expected to have an accuracy (s) better than 5 cm. The errors of image measurement and very small uncorrected ω-tilts are regarded as the main sources of error, as expressed in the repeatability (σ) of measurement, which represents precision.

Finally, let it be noted that the accuracy of the method is independent of road slope, since the camera axis follows this slope, while small tilts are corrected through the vanishing points. It must be stressed, however, that the validity of the proposed method holds only for the object plane on which the car proceeds. For roads with variable superelevation rates among lanes, the approach is only valid for the lane on which the camera platform moves.

5. DEVELOPMENT OF THE GIS-T

A prototype software, named *Hellas Roads*, was designed and developed for managing - storing, retrieving and portraying - the information collected by the system. *Hellas Roads* is a typical Transportation GIS (GIS-T) software [*Waters, 1999*] which integrates and represents in a digital environment the geometric and thematic characteristics of the road axis. The geometric model of the software is based on three types of graphical objects: linear segments, circular arcs and spiral curves (clothoids), which are successively connected and form the axis of the road network. The thematic characteristics of the road network are qualitative or quantitative attributes (like: traffic signs, elevations, slopes, radii of curvature, etc.) organized in a relational database and associated with the road geometry through stationing. Spatial information is geo-coded using the National Geodetic Reference System of Greece, which is based on planar co-ordinates of transverse Mercator projection. The software was designed to fulfill the following four basic characteristics:

- To operate under different computer platforms.
- To be addressed to users not necessarily computer or GIS specialists.
- To be open for further revision, modification or upgrading.
- To support users decisions on improving the design of an existing road.

The software allows users to interact friendly with the computer in order to have access with the stored database content of the road network. The user can browse the stored information by performing specific queries. The software responses to the queries present the retrieved data in form of tables or graphical views. The graphical views are typical diagrams of horizontal/vertical alignment, superelevation rates and runoff, grades and horizontal/vertical curvature radii. Furthermore, a comprehensive graphical library was created to portray all legally defined traffic signs. Figure 7 illustrates four characteristic examples of graphical views created with *Hellas Roads* software. User can export the results of the analysis as ASCII text files in case that these are presented in table form, or as AutoCAD Interchange File Format (DXF) in case that the results are presented in graphical form.

The prototype software was developed using *Microsoft Visual Basic* object-oriented programming language. The thematic data were organized and stored using *Microsoft Access* database management software platform. The prototype software operates under the existing PC operating systems (*Microsoft Windows 95-98-98 Millennium-NT v.4.0-NT 2000*). Currently, a study is in full operation in order to transpose *Hellas Roads* software under *ArcView* software platform.

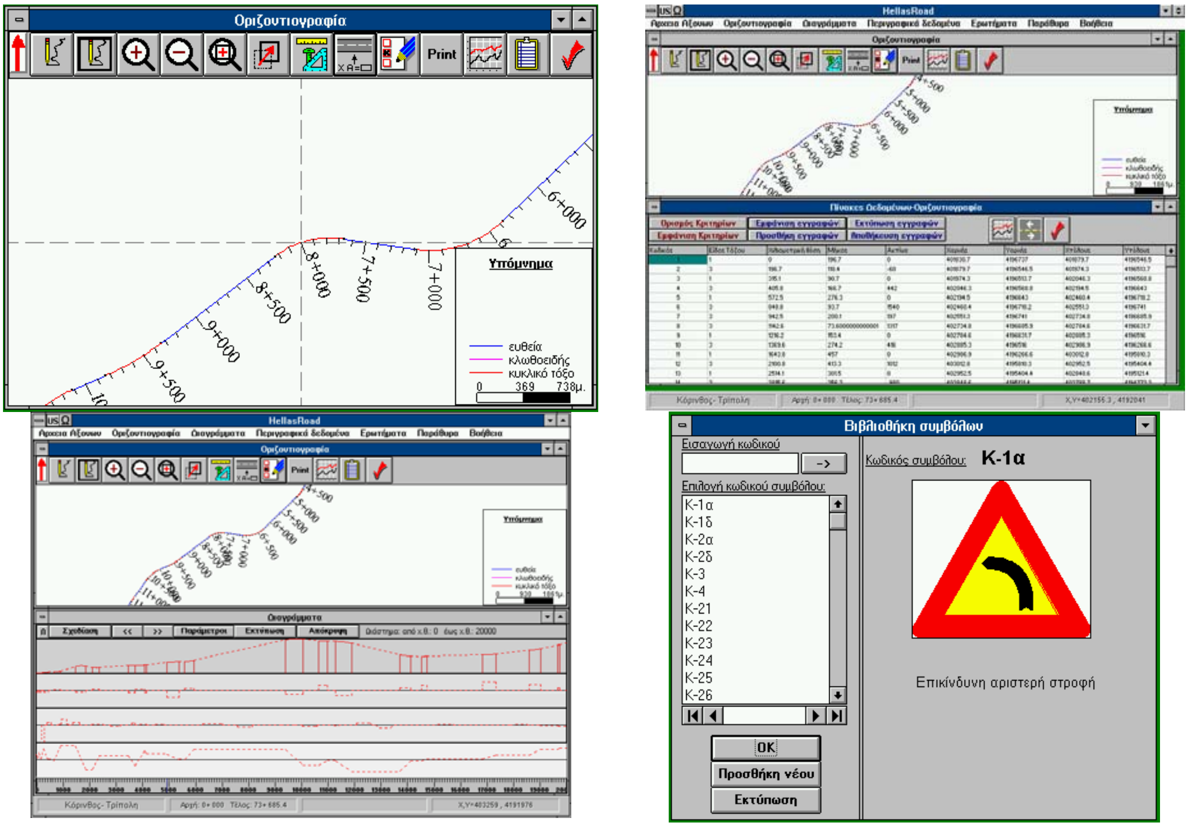

Figure 7. Characteristic graphical views of *Hellas Roads* software.

6. CONCLUSIONS

The road surveying system described briefly above represents a cost-effective system developed to address and fulfill the user requirement philosophy and has been tested satisfactorily on 1.300 km of the national road network. The data-recording rate on the roadway correspond to an average speed range of the van ranging from 20-70 km/h depending on road category (multiple lane divided highways, 2 lane highways etc.), although 80% of the covered roadways were traversed at a mean speed of 36 km/h (10 m/sec), reflecting an optimum data density recording. The on site performance of the system ranged between 100-150 km/day, depending on the road category. The operational cost of the system for data recording was of the order of ca 550 € /day all-inclusive.

The developed system is further to be upgraded both in relation to its hardware as well as to its software in order to:

- include a dead reckoning or an inertial navigation system combined with a Kalman filtering process to warrant a continuous data recording within shadow areas, where satellites are not enough or completely missing, i.e. in tunnels;
- include a system component for measuring cross section data beyond the crone width of a roadway, i.e. side-slopes etc. as well as geometric features within a curved section such as curve widening;
- expand the capabilities of the developed GIS-T and to make it compliant with conventional GIS software packages found in the market to facilitate data exchange.

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