A MOBILE MAPPING SYSTEM FOR ROAD DATA CAPTURE VIA A SINGLE CAMERA

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ABSTRACT:

The development of road telematics requires the management of continuously growing road databases. Mobile mapping systems can acquire this information, while offering an unbeatable productivity with the combination of navigation and videogrammetry tools. However, such technically advanced devices go together with significant investments in staff and hardware. The geodetic engineering laboratory continues developing a user-friendly and low-cost process of extraction of road data. The system allows a subdecimeter restitution of the road centerline, after a B-spline interpolation. New investigations involve the use of national-wide RTK positioning service via cellular communications, and the use of a nearly horizontal camera for the monoscopic survey of road signs. The first results are satisfactory, reaching an accuracy of 20-40 centimeters with respect to the central axis of the road in most conditions.

RÉSUMÉ:

Le développement de la télématique routière des transports réclame la gestion d'une quantité sans cesse croissante de données rattachées à l'espace routier. Des systèmes de lever topométrique mobile peuvent acquérir ces informations, en offrant un gain sensible de productivité grâce à la combinaison d'outils de navigation et d'imagerie numérique. Néanmoins, de tels systèmes, à mise en œuvre délicate, imposent un investissement financier considérable tant du point de vue matériel qu'humain. L'Unité de Topométrie engage donc des recherches dans l'élaboration d'un procédé d'extraction de données routières convivial et peu onéreux : le projet *Photobus*. Ce dernier autorise une restitution de la ligne centrale de la route, après interpolation par B-splines, d'une précision sub-décimétrique. De nouvelles investigations impliquent le service national de diffusion de corrections RTK via réseau GSM, et l'utilisation d'une caméra horizontale pour le levé monoscopique de panneaux routiers. Les premiers résultats sont satisfaisants, à savoir une localisation par rapport à l'axe central de la route avec une précision de 20-40 centimètres.

1. INTRODUCTION

In Switzerland, STRADA-DB disposes of all the data needed by the services of road maintenance, i.e. the features of the pavement, its structural and functional state, as well as all the events and activities that influence the exploitation of the roads. The spatial referencing represents a crucial point for this database. Each road data is linked to marked or painted points whose position is defined within a linear referencing system. This curvilinear coordinate system is currently under review, which initiated the design of a mobile mapping system for the automatic determination of the road geometry: the *Photobus* by the Geodetic Engineering laboratory of the Swiss Federal Institute of Technology Lausanne. Similar to VISAT (Schwartz and al., 1993) or the GPSVan (Goad, 1991), our system exploits the concept of direct georeferencing, i.e. the instantaneous definition of the orientation parameters of a progressive scan camera, by combination of navigation sensors. All sensors are mounted on top of a van on an easily portable roof-rack.

Our mobile mapping system can be distinguished from its predecessors by its ability to georeference the road centerline through a vertically oriented camera (Gilliéron et al., 2000). Such a monoscopic technique is simple and economically appealing for rendering the road layout with sub-decimetric accuracy. Following these encouraging results, we focus our investigations on the acquisition of additional road data by a nearly horizontal camera.

2. THE SYSTEM PHOTOBUS

2.1 Design

The mobile mapping system *Photobus* combines an accurate positioning by GPS/INS measurements with a progressive scan camera (cf. Figure 1). An embedded system guarantees the synchronization of navigation data with imagery.

2.1.1 Navigation sensors: When operating in higher speeds in quickly changing surroundings, any global application of precise trajectography requires high-performance GPS receivers with instantaneous re-acquisition of signals after a loss. The dual frequency receivers Javad Legacy GD live up such expectations, providing complete raw data and position results up to 20 times per second. To ensure a use of the system under a poor GPS coverage, a tactical grade inertial measurement unit Litton LN200 measures angular velocities and linear accelerations in the three directions roll / pitch / yaw, at a 400 Hz.

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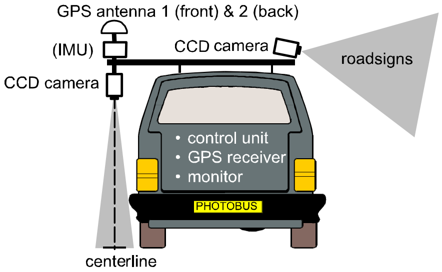

Figure 1. The system *Photobus*

2.1.2 Video sensor: The camera Sony XC-55 is a charge-coupled device that grabs frames at 20 Hz. It uses square pixels whose side is 7.4 µm long, which eliminates the need to apply corrections of non-unity aspect ratio distortion.

2.1.3 Data synchronizing: The selection of the hardware focuses on the ability to swap TTL (Transistor to Transistor Logic) signals that can synchronize navigation data with grabbed images in the GPS time frame. This allows to georeference the captured video. Moreover the embedded version of the Windows operating system minimizes the latency due to the management of the interrupts following the collection of data.

2.1.4 GPS positioning: A road survey usually involves journeys superior to 10 km, distance beyond which the real-time resolution of ambiguities is less reliable. The Swiss Federal Office of Topography offers a national-wide RTK positioning service via cellular communication (Wild, Grünig, Hug and Kummer, 2001). Once the GSM connection established, the user provides his approximate position via a NMEA message. Thanks to this position, the communication server *Swipos* defines the triangle of the permanent GPS network that best fits. Then it computes an interpolation of a virtual reference which is only a few meters far from the user. The rover of the latter interprets the transmitted data as if they were broadcast by a real RTK reference. The figure 2 shows the coverage of the service *Swipos.* The use of this service allows us to avoid the post-processing of GPS measurements, while keeping an accuracy of about 5 centimeters. However, it is mandatory to reset the GSM connection every 15 km.

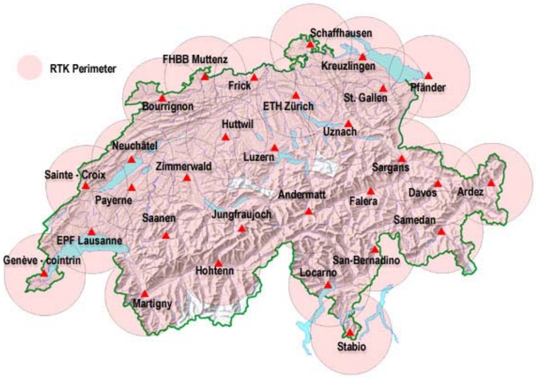

Figure 2. The Swiss GPS permanent network

2.1.5 Integrated positioning: The GPS-RTK solution provides aiding to the loosely-coupled inertial navigator. Further aiding comes in the form of GPS-derived azimuth and the distance from an optical odometer. In the periods of long and complete shading of the satellites, the method of Zero Velocity Updates (ZUPT) is applied.

2.2 System calibration

2.2.1 Hardware lay-out: All the sensors are mounted on an easily portable roof rack. The GPS antennas are set parallel to the left side of the vehicle. Consequently, they define the position and the azimuth in case of a good GPS visibility. Otherwise, the inertial unit below the front antenna assures continuity in measuring accelerations and angles. On assuming that both GPS antennas make a reference frame [OX_{BODY}, Y_{BODY}, Z_{BODY}], the camera is located in the extension of OX_{BODY} axis (cf. Figure 3).

2.2.2 Calibration of the vertically-oriented camera: The georeferencing of video imagery exploits a procedure of calibration that allows defining a transformation between the coordinates in the picture and reference frames. This simple operation is carried out after each setting up of the *Photobus* hardware. For details about the calibration of the vertically-oriented camera, see (Gilliéron et al., 2001)

2.2.3 Calibration of the horizontally-oriented camera: In the Canton of Vaud a uniform signalization is provided by the company *ELGA signalisation AG*. The road signs are erected on poles that measure 6 cm in diameter. Therefore, the calibration sheet presents a regular mesh of identical circular targets, and is stretched on nearly vertical railings, of known azimuth. The *Photobus* is set parallel to these railings, thanks to the real-time computation of its azimuth with two GPS receivers operating in RTK mode. The picture of the mesh captured by the camera is linked to a frame [TX_{PIC}, TY_{PIC}] (cf. Figure 3). To reach the metric coordinates of the targets, this picture is divided into small areas to which their own transformation parameters are attributed. Lying on the finite elements methods, such a technique allows reducing the incidence of any type of distortion without complex computations (Tecklenburg et al., 2001).

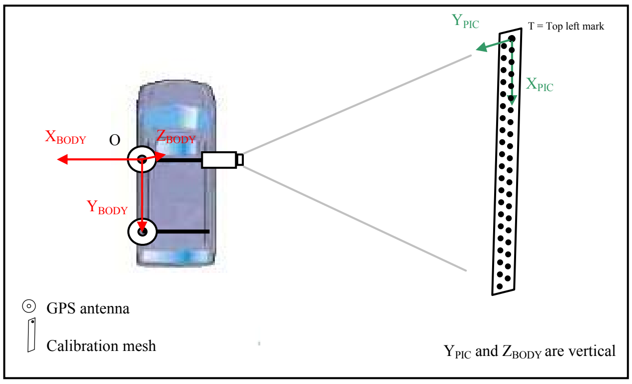

Figure 3. Coordinate system and calibration

Once the coordinates of each pixel are expressed in the calibrated picture frame, they undergo the combination of the symmetry in relation to the axis X_{PIC} with a translation, in order to compute their expression in the body reference frame (Equation 1).

$$\begin{bmatrix} Y_{BODY} \\ Z_{BODY} \end{bmatrix} = \begin{bmatrix} X_{PIC}^{cal} \\ -Y_{PIC}^{cal} \end{bmatrix} + \begin{bmatrix} T_Y \\ T_Z \end{bmatrix} \tag{1}$$

where T_Y and T_Z are the coordinates in the body reference frame of the target located on the top left corner of the calibration sheet.

The determination of the coordinate X_{BODY} lies on the proportionality between the distance that separates the considered target from the plane $OZ_{BODY}Y_{BODY}$ and the pixel size of this target. On assuming that the optical axis of the camera cuts the picture of the calibration sheet across its center, the target neighboring the point of intersection shows an apparent diameter expressed in pixels. It follows that there is a relationship between X_{BODY} and the pixel size of the pole holding the signal. (cf. Equation 2).

$$X_{BODY} = \frac{X_{BODY}^{Calib} \cdot p^{Calib}}{p^{pole}} \tag{2}$$

where X_{BODY}^{Calib} : distance, expressed in meters, separating the calibration sheet from the axis OY_{BODY}.

p^{calib} : pixel size of the target neighboring the center of the picture of the calibration sheet

p^{pole} : pixel size of a pole of a road sign

This formula is valid if the road sign to survey is in the center of the picture ($Y_{BODY} = 0$), which is normally the case. Otherwise, the following equation is applied:

$$X_{BODY} = \sqrt{\left(\frac{X_{BODY}^{Calib} \times p^{Calib}}{p^{pole}}\right)^2 + \left(Y_{BODY}^{pole}\right)^2} \tag{3}$$

where Y_{BODY}^{pole} is the coordinate following OY_{BODY} of the axis of the pole.

The standard deviation due to the picture component is about 10 cm on outward/return trips: a result of the same order as the error inherent to the differential GPS positioning used to georeference pictures.

2.3 Surveying road signs with Photobus

The monoscopic survey of road signs with *Photobus* was under tests on a section of road with an excellent GPS visibility. Therefore, the use an inertial platform was not necessary. The road centerline is routinely surveyed by our mobile mapping system. For example, see (Gilliéron, et al., 2001).

2.3.1 B-splines interpolation: *Photobus* provides the coordinates of the road centerline in the Swiss coordinate system (Y, X, H). However, the inventory of road data within STRADA-DB uses a linear coordinate system that is linked to this axis of the road. Hence, we must transform the national coordinates into suitable coordinates by carrying out a parameterization of the road axis based on curvilinear abscissa.

Since a set of points surveyed by the mobile mapping system *Photobus* define the centerline in discrete way, we compute an interpolating curve, under the shape of a cubic spline whose parameter is the GPS time *t* (cf. Equation 4). In most systems, a linear piecewise interpolation is considered to be sufficient as the interpolation error gets minimized by sufficiently high sampling rate. Using such representation is, however, not appropriate when the existence of continuous first or higher order derivatives is needed, as in a system of curvilinear coordinate system.

$$f(x,y) = \bigcup_{i=0}^{n}\left(a_i t^3 + b_i t^2 + c_i t + d_i\, , e_i t^3 + f_i t^2 + g_i t + h_i\right) \tag{4}$$

Using piecewise cubical spline (Figure 4):

- Satisfies the conditions of continuity
- Allows re-parametrizing by the curvilinear abscissa
- Represents the best fitting curve with a minimal number of points.
- Allows getting very satisfactory results for the curvilinear abscissa of any road object (Atkinson, 2002).

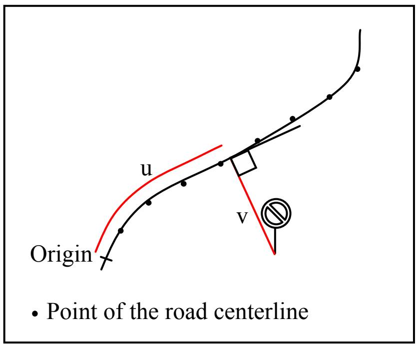

Figure 4. A road data and its coordinates in STRADA-DB

The computation of the lateral offset of a road sign in relation to the road axis implies three steps:

- Determination of the tangent to the spline for the curvilinear abscissa of interest.
- Rotation of the *BODY* frame around O, so that the axis OY_{BODY} is parallel to the tangent.
- Computation of the offset by adding the distance from O to the above-mentioned tangent with X_{BODY}.

2.3.2 Results: 15 road signs were surveyed on this 3-km-long section. To validate the method, we compared the coordinates of signals computed by the monoscopic survey and by GPS RTK (Table 1).

Road sign	Difference on curvilinear abscissa (u)	Difference on lateral offset (v)
Mean	0.17 m	-0.82 m
Std deviation	0.15 m	0.40 m

Table 1. Surveying road signs with *Photobus*

The empirical accuracy complies with the requirements of the inventory of road signs, since the services of road maintenance allows a maximal error of 1 meter for the curvilinear abscissa. The difference on the lateral offset is systematically negative, probably because of the poor (320×290) resolution of the camera. However, the expectations on the accuracy of the lateral offset are not defined.

3. PERSPECTIVES

3.1 Enhancement of calibration

The method of calibration presented in this document eliminates the distortion for the objects that are located at the same distance from the camera as the calibration sheet. However, *ELGA signalisation AG* does not only provide poles of 6 cm in diameter in the Canton of Vaud. Their catalogue indicates galvanized tubes of 48 mm, 60 mm, 76 mm, 114 mm, 139.7 mm in diameter. These tubes are selected according to the location and the dimensions of the signal to hold. Investigations are in progress to determine if the induced errors are tolerable; a more rigorous calibration should guarantee even better results.

3.2 Identification of road signs

The mobile survey of road signs makes a promising start at the Geodetics laboratory thanks to the direct georeferencing of a video captured by a horizontal camera, nearly perpendicular to the road axis. However, the camera orientation does not allow for an acceptable signal identification which is required for its interpretation. (cf. Photos 1 and 2).

Photos 1 & 2. The identification a road sign can be difficult

We currently investigate the implementation of a tool combining GPS and a digital camera, to update the inventory of road signs in a semi-automatic way with:

- A clear shot of the road sign, for an automated interpretation
- A GPS time stamp of this shot, allowing a fast retrieval of the video sequence to georeference road signs.

3.3 Towards a real-time survey

Such a monoscopic technique is sufficient to render the road lay-out with sub-decimeter accuracy. Moreover, the georeferencing attributes national coordinates to all pixel form the video imagery, so that the productivity is very satisfactory. However, the complexity of the processing of navigation data, and their merging to video sequences, involve substantial work, accomplished by a highly-qualified staff. Besides, the current processing of the video imagery is semi automatic and requires a control from the operator, for an optimal control of the reliability of the pixel measurements. At last, only the results of post-processing show that the navigation performance is of sufficient accuracy.

Ideally, the implementation of a real-time or slightly delayed processing of the data captured by a mobile mapping system can limit the human intervention to the collection of data on the field and bring the quality control of data collection directly in the field. This evolution is the subject of a research in the Geodetic Engineering Laboratory.

4. CONCLUSION

The update of road databases is a crucial stake for the maintenance and the security of the road network. *Photobus* presents a technological solution that is simple, productive and economical. Our first experiments of a monoscopic survey of road signs are conclusive and direct our future efforts towards the automation of video processing.

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