OPTIONS FOR USING IP-S2 TOPCON FOR MOBILE MAPPING NEEDS

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Abstract

This paper explores digital geoinformation data acquisition with use of progressive mobile mapping technologies. Modules of the IP-S2 TOPCON mobile mapping system, field data acquisition, and data post-processing possibilities are described. Testing of trajectory accuracy, which is important for practical mobile mapping system applications in various fields of interests, is explained. In the last part of paper, practical applications of the mobile mapping technology are discussed.

Keywords: Mobile mapping (MM), GIS, MM data processing, Panoramic images, Panoramic video, Laser point clouds, City Invetarisation.

1. Introduction

The technological development in the area of acquiring and processing of recordings from *GNNS* receivers combined with recordings from inertial measurement units (*IMU*) has progressed dramatically, with several new devices gradually appearing on the market. These devices can be used for handling various technical tasks relating to data acquisition for mapping or GIS application needs. The applications are referred to collectively as mobile mapping methods. Continuous development of technical resources of *GNSS/INS* systems and mainly the shift in data processing led to the situation when some of the existing systems on the market provide truly impressive results – in terms of data acquisition speed, data density, resulting position accuracy, and also price of the data acquired. World's leading manufacturers of these devices, such as *TOPCON*, *Trimble*, *NovAtel*, *Applanix* have been concentrating mainly on improving their system accuracy in situations when *GNSS* outages appear. With integration of two navigation technology types that act complementarily, mobile mapping systems (MMS) are able to quickly recover signal reception whenever signal is lost, handle *ambiguity* and resume fixed solution. The achieved level of accuracy then directly determines usability of these systems for selected applications.

2. Mobile Mapping

Mobile mapping refers to a unique technology enabling fast and mainly efficient geoinformation data acquisition, mainly in urban areas where infrastructure changes rapidly, such as buildings, lawn and planting, communications etc., and where it is not possible to perform sufficiently effective documentation using traditional mapping means. The core of this technology are mobile mapping systems that can be installed on vehicles, ATWs, ships, helicopters and other flying means and that are used for the actual in-field data collection.

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This technology includes also applications for post-processing the acquired data and evaluating information of interest.

2.1 Mobile Mapping System Configuration

Although there are minor differences among mobile mapping systems of different manufacturers, some elements are common. Gradual development of the systems generated certain unification efforts, meaning that there is possible to see a move from the original systems that were often literally rigged up on roofs of mobile means to sophisticated solutions with a control unit, *GNSS* receiver, *IMU* and external odometers attachable to vehicle wheels. The odometers can be replaced with a *CAN-BUS* directly cooperating with the communication interface of the car. These devices constitute the core and are used mainly for determining the mobile mapping system position and data georeferencing from sensors that are used for the actual documentation of the interest area. These devices include mainly various types of digital cameras and laser scanners. The entire system is mostly operated by a controller computer, usually an industrial computer or notebook adjusted for data collection needs. It is mainly the capacity and speed of hard drives, processors performance and graphic adapter performance that need to accommodate high demands. However, communication interfaces are equally important as they ensure communication and data transfers between the computer and MMS. A certain communication standard are serial ports, both physical and virtual (e.g. Ethernet-based). For digital camera data transfers, gradual development resulted in three most commonly used solutions for transferring large data volumes: *GigE Vision®*, *FireWire* and *Camera Link*. In some situations when cameras with lower resolutions are applied, the classic *USB* interface can be utilized as well.

The number and placement of digital cameras depends mainly on the type of application for which the data is captured and the method of acquiring information from images. For some applications it is useful to position cameras so that acquired images form stereoscopic pairs and allow for stereo measurements. On the other hand, in some situation cameras are pointing in opposite directions or are located on cross limbs so that the maximum coverage of the surroundings of the system trajectory is achieved and hidden areas are minimized. Evolution of the objects of interest is then based on spatial intersection of images.

Some MMS are equipped with laser scanners. At the beginning of the MMS development only 3D laser scanners were used that allowed to scan surroundings of the vehicle in a static mode after it came to stop or capture digital images. Systems comprising multiple scanners are now more popular, i.e. 2D scanners that perform scanning of the surface in a dynamic mode while the system is moving along its trajectory. The third dimension is thus obtained as a result of the scanner location changing in time. The configuration of scanners on the vehicle is variable, depending on the number and type of scanners and the required output of scanned data.

2.2 IP-S2 Topcon Mobile Mapping System

One of the aforementioned producers of MMS is *TOPCON* CORPORATION, offering custom-configured systems matching customer's demands. Fig. 1 shows one version of the basic system configuration mounted on a vehicle, where the actual mobile mapping system is located on a tilting holder about 3 m above the ground.

Fig. 1 Basic IP-S2 mobile mapping system configuration

The basis of this system is the IP S2 *Cube* calibrated construction on which a control units is mounted, *IP-S2 box*, which is connected to a computer using an Ethernet cable. All other devices are connected to this unit, with basic parameters listed in the table below:

GNSS COMPONENT	
Channels	40 channels, all-in-view, L1 GPS, L1/L2 GPS, L1/L2 GLONASS, L1/L2 GPS + L1/L2 GLONASS, WAAS
Low signal tracking	Down to 30 dBHz
Cold / warm start	< 60 sec / < 10 sec
Reacquisition	< 1 sec
Vibration	Up to 30 g's of dynamic
Advanced firmware function	Multipath Mitigation, Co-Op Tracking
Real time position & raw data	Up to 20 Hz update rate
RTCM SC104 v2.1 and 2.2	Input /Output
NMEA 0183 v2.1, 2.2, 2.3 & 3.0	Output
IMU	
Data rate	100 Hz
Gyro bias/drift rate	1°/hr
POWER	
Input supply voltage	9V to 28V
PHYSICAL	
Size / weight	20 cm x 23 cm x 11 cm / 3.6 kg
ENVIRONMENTAL	
Temperature operating storage	-30° to +60°C -45° to +80°C

I/O PORTS	
CAN Bus	OBDII - MOLEX-9 Pin
Encoder	TTL quadrature input
Ethernet	100 Base-T
USB 2.0	Host input /output
RS-232-/422	Up to 2 Mb/s
High-speed digital I/O (x4)	LVDS 400 Mb/s
LASER SCANNER	
Scanning angle/angular resolution	180°/1° Angular Resolution - option side looking 2 x
	90°/0.5° Angular Resolution - option back looking 1 x
Typically measurement accuracy	± 45 mm
Typical range	30 m
Date rate	75 Hz via Ethernet
SPHERICAL DIGITAL CAMERA	
Image sensor	Sony 2.0 MP 1/18” ICX274
Max resolution	1600x1200 (HxV)
Frame rate (max resolution)	15 FPS JPEG compressed
Optics	Six high quality 3,3 mm focal length microlenses
Panorama stitching resolution	5400x2700

Tab. 1 Parameters of devices comprising the IP-S2 mobile mapping system

In addition to the control unit, the system contains a dual frequency *GNSS* receiver capable of receiving signal both from *GPS* and *GLONASS* satellites at the data recording frequency of 10 Hz. The *IMU* in use with the frequency of 100 Hz and gyro bias / drift rate of 1°/hr manufactured by *Honeywell* offer quality comparable to that of e.g. *IMU Litton 200* or *IMAR FSAS* that belong among the best devices in this category in the world. For applications with lower requirements for the output accuracy, inertial measurement units based on the *MEMS* technology can be used. Two external odometers and/or information from the *CAN-BUS* interface of the vehicle are used to accurately determine the MMS velocity. The basic version of *IP-S2* is equipped with a special spherical camera and three laser scanners. Two of them are mounted on sides and one is pointing to the front or rear of the vehicle, depending on the configuration. With respect to customer requirements, the system supports up to six classic digital cameras suitable for mobile mapping and also up to six laser scanners. Sensor synchronization is maintained by a special time board with the internal accuracy of 15 ns.

2.3 Data Acquisition Using the IP-S2 Mobile Mapping System

The first step of mobile mapping involves data collection in the area of interest. The system is controlled using a web-based application where users can monitor proper functioning of individual devices and set their parameters. The parameters include offsets and mutual orientation determined within calibration. For digital cameras, it is possible to select from two exposure control modes. The fist mode is based on time intervals and the second, more frequently used, on distance intervals, where camera exposure is controlled depending on the traveled distance. The data acquisition density is therefore fully within user’s control. Once data acquisition parameters are set and data recording is launched for all sensors, it is usually necessary to wait a moment before commencing the drive and collecting static data. The static data is needed for the process referred to as *static alignment* that can be perceived as a method for computing *IMU* orientation initialisation values. *Kinematic alignment* is used in practice too, where no static data is required and mainly *IMUs* based on the *MEMS* technology are used. In both cases it is beneficial to perform both the *static alignment* and then *kinematic alignment* at the data acquisition start. For the latter it is recommended to drive in such a way that *heading* changes are as large as possible and the computation process has sufficient data for proper system position and orientation calculation. Considering the path computation is performed both in the "forward" direction and the "backward direction", the data acquisition needs to be completed in the same way as it was started. The path should always start in areas with good *GNSS* coverage, ensuring quality positioning. Incorrect initialisation process performance can result in destroying several hours of measurement. Hence it is a good practice to sacrifice a couple of minutes both at the start and at the end, guaranteeing good results.

2.4 IP-S2 Mobile Mapping System Data Processing

Once acquired in the field, the data needs to undergo post-processing, which can be divided into three steps for *IP-S2* MMS. The first step is calculation of the MMS trajectory since the trajectory is used as a basis for all sensor orientation and position calculations to follow. The other two steps involve processing of images from digital cameras and data from laser scanners.

The trajectory calculation method is based on integration of data from a *GNSS* receiver, *IMU*, external odometers and *CAN-BUS*, allowing to achieve required accuracy even in areas where the *GNSS* positioning alone is unreliable or entirely impossible. This happens mostly in urban areas where signal from satellites is often blocked by high buildings, trees and other objects. The absolute system position calculated using the *GNSS* technology serves for compensating errors in measurements obtained from the inertial measurement unit. On the other hand, the relatively stable position (in a short-term scope) determined by *IMU* can be used to overcome areas where *GPS* fails. Additional information is received from odometers measuring speed and distance travelled depending on the rotation of wheels and/or *CAN-BUS* of the vehicle. There are two trajectory calculation methods that became widely used in practice, referred to mostly as *loosely* and *tightly coupled*. Both methods utilize Kalman's filters while when the *loosely coupled* method is applied, the path is pre-calculated using the *GNSS* differential method first. This path is then used when processing *IMU* data to update position and speed. When the *tightly coupled* method is used, the *GNSS/INS* data is processed simultaneously, making it possible to use at least two satellites for a phase update, which means a great advantage in difficult conditions with limited satellite signal reception.

Image data processing depends on the type of digital cameras in use. Some cameras store images directly in classic formats, such as *JPEG*, *TIFF* or *BMP* while others use various *raw* formats instead to increase the data transfer rates and capture up to tens of hi-res images per second. This makes the demands for data post-processing even higher. If *IP-S2* and a special spherical camera is used, panoramic images are created during post-processing with the high resolution of 5400x2700 pixels. For these image calculations of exterior orientation parameters are added based on the trajectory calculated. The resulting data can be used for example in the *PanoramaGIS®* application that has been developed by *GEODIS BRNO* for this purpose (see Fig. 2) and is based on the ground photogrammetry principle.

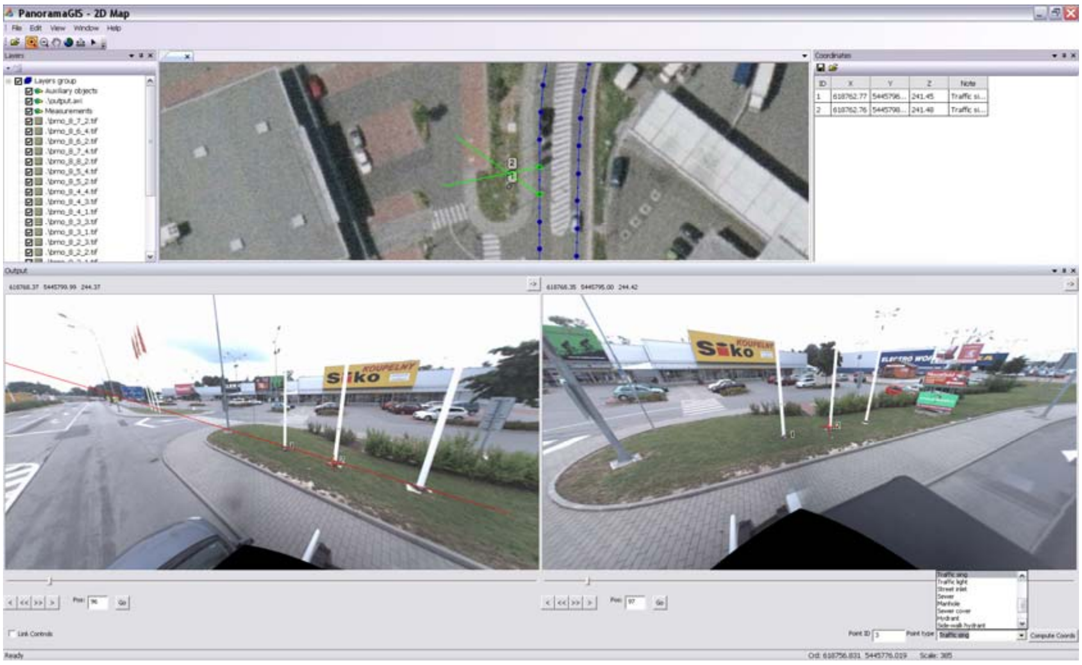

Fig. 2 PanoramaGIS® workspace

The last step includes laser point clouds processing measured data, representing information on transit times of emitted rays and the incoming light intensity is converted to a cloud of laser points. Colours can be assigned to the points using the images captured, creating a realistic 3D model of the area of interest. Every laser point – and there are several tens of millions of these created within data collection – carries information on the position, reflection intensity and colour, which is usually stored as RGB. To evaluate information from laser point clouds it is possible to use directly the *Spatial Factory* application developed by *TOPCON* for data acquired with the *IP-S2 MMS* (see Fi.g 3).

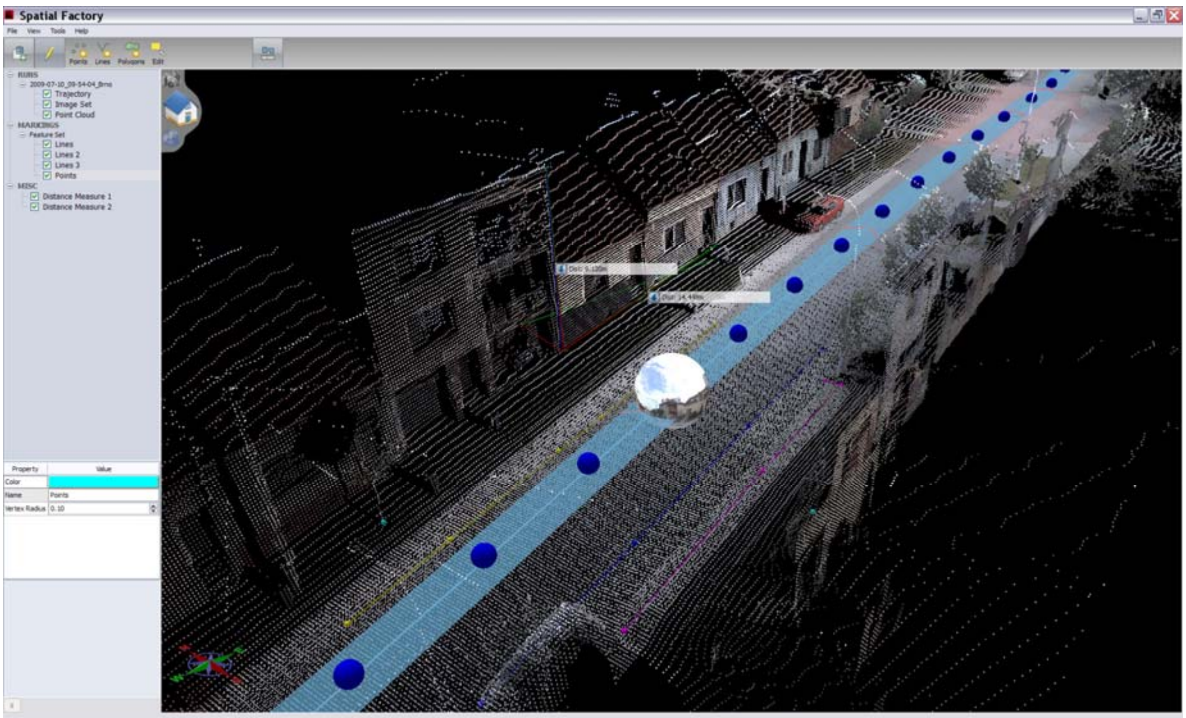

Fig. 3 Spatial Factory workspace

The data processing involves also transformation of outputs to selected national coordinate systems. For exterior orientation parameters this requires significant amount of knowledge when converting orientation angles and for laser points a quality algorithm is needed to transform files containing several gigabytes of information.

2.5 Partial Verification of the System Functionality and Accuracy Analysis Using a Testing Polygon

The *IP-S2* mobile mapping system developed by *TOPCON* in cooperation with *GEODIS BRNO* was subjected to verification using the testing polygon constructed on the D1 highway in the section from Kývalka to Holubice and the D2 highway from the junction with the D1 highway to Blučina. Over 40 km have been travelled here within test drives when images were captured in the distance of 2.5 m.

A part of the test discussed here focused on verifying and testing the accuracy of trajectory computation. The analysis was based on exterior orientation parameters obtained during post-processing, or in fact only on their projection centres Z-coordinates. The testing of this coordinate component calculation assumed that the height of camera above the ground should be constant when driving on a highway. If we know the digital terrain model (DTM) in areas where the data was acquired, we can calculate the height of the camera as the different of the projection centre Z coordinate and the Z coordinate of the ground projection of the projection centre. The distance obtained in this way can be compared to the actual camera height and certain accuracy characteristics can be derived form the deviation. Hence the Z coordinate deviation of the i-th projection centre Δ_{Zi} has been calculated using the below formula:

$\Delta_{Zi} = h_{syst} - (Z_{EOi} - Z_{DTMi})$ where
h_{syst} .... vertical distance measured from the ground to the spherical camera centre
Z_{EOi} .... Z coordinate of the i-th projection centre (from exterior orientation parameters)
Z_{DTMi} .... Z coordinate of the i-th projection centre (projection to DTM)
$i = 1, .. n$ ... number of projection centres tested

The basic prerequisite of testing is using a DTM with sufficient accuracy, which was obtained in this case by surveying two sections (DTM-1 and DTM-2). Each section was 4 km long, with measurement step of the longitudinal elevation profile approx. 5 m and measured using the accurate levelling method. The accuracy of such model on a highway is greater than 1 cm. Based on the deviations calculated, the mean error σ_Z was obtained for the first and second section using the below formula:

$\sigma_Z = \sqrt{\frac{\Sigma \Delta_z^2}{n}}$, where
Δ_{Zi} .... deviation of the Z coordinates for the i-th projection centre
n .... number of projection centres tested

The following two charts display values of calculated deviations. In total there were 1 514 projection centres compared for the first section (DTM-1) and 1 555 projection centres for the second section (DTM-2), which ensures a sufficiently large data sample to calculate accuracy characteristics.

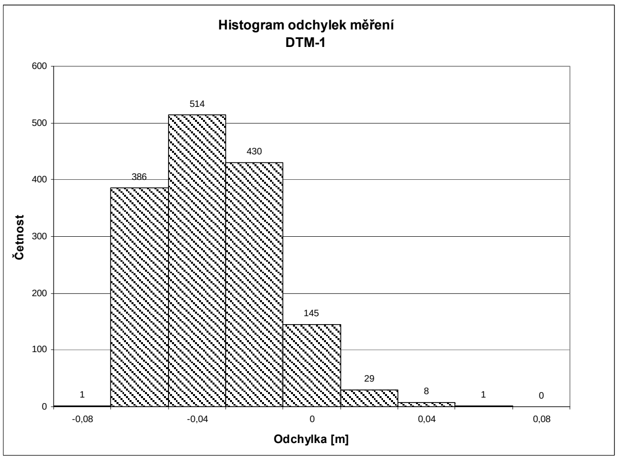

Chart 1: Histogram of deviations calculated for the DTM-1 section

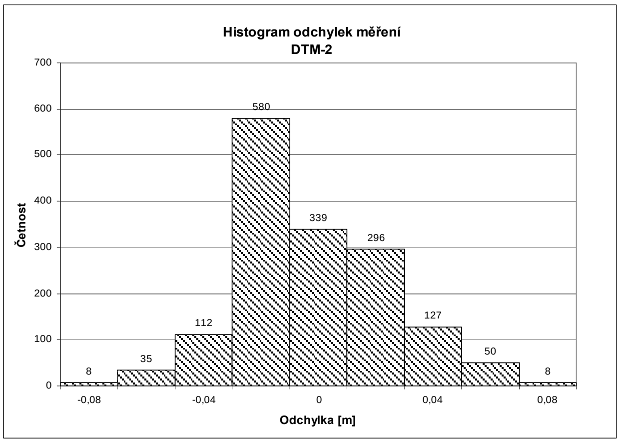

Chart 2: Histogram of deviations calculated for the DTM-2 section

The histogram of deviations on the DTM-1 section (Chart 1) shows normal distribution of deviations Δ_Z with possible systematic effects given by the translation of the histogram centre to $\overline{\Delta}_{DTM-1} =$ -0,044 m. Analysis of the second histogram (Chart 2) shows normal distribution of deviations Δ_Z, again with possible systematic effects since the centre is translated to $\overline{\Delta}_{DTM-2} =$ -0,012 m. Assuming there are no significant errors in the measured data, we can consider the average value of the measurement error $\overline{\Delta} = \frac{1}{n}\sum_{i=1}^{n}\Delta_{Zi}$ as the estimate of its systematic component and the difference $\overline{\Delta} - \Delta_{Zi}$ as the estimate of its random component. For the final calculation of mean errors σ_Z, effects of supposed systematic errors $\overline{\Delta}_{DTM-1}$ and $\overline{\Delta}_{DTM-2}$ have been removed from the testing sets. Their occurrence will be a topic of further testing; however, their influence can be most likely attributed to insufficiently accurate calibration where offsets of individual devices had not been determined. Results are summarized in Tab. 2.

	σ_Z [m]
DTM-1	**0,020**
DTM-2	**0,028**

Tab. 2 Mean errors calculated

3. Conclusion

Mobile mapping systems are capable of fast acquisition of large amounts of geoinformation data with required detail and accuracy. MMS capture essentially a virtual reality image when acquiring data – a task that would be hard to accomplish for a person in the field, especially on streets during rush hours. The acquired data are rich with information that can be extracted in the comfort of an office, either visually or using programs designed for this purpose. This saves times while increasing the efficiency of human activities. A great advantage is also the option of fast data updates using mobile mapping systems that are able to perform detailed mapping of tens of kilometres of communications and surrounding areas per day (depending on traffic).

Considering the accuracy achievable with mobile mapping systems, which was verified by means of testing, the mobile mapping technology can be applied both to tasks with lower accuracy demands and to highly demanding data acquisition mapping procedures on highways and fast communications, where accuracy of mean measurement errors should be greater than 0,03 m. The mobile mapping will find its applications also within passportization of road signs, road facilities, utility grids and lawn and planting as well as urban planning and 3D modelling of cities with subsequent visualization. The collected data can serve even needs of integrated rescue systems, providing valuable information on the real spatial situation, for example to firefighting squads, rescue service, police, or units dealing with dangerous gas leakages.

Literature

[1] Advances in Mobile Mapping Technology, ISPRS Book Series, ISBN 978-0-415-42723-4

[2] IP-S2 TOPCON Technical Documentation