Photogrammetry and GPS technology assisting the acquisition of road geolocation and geometry

Uroš Ranfl

DFG CONSULTING, d.o.o., Ljubljana, Slovenia

Keywords: GPS, photogrammetry, digital video, state roads geometry

Abstract

Georeferenced data present state of the art in the road data management. They are accessible directly in state coordinate system and therefore easily connected into existing geospatial databases. In this paper we present the concept, technology, possibilities and practical experiences on a low cost mobile mapping system (named VideoCar) developed for road data acquisition in Slovenia. Accurate georeferenced measurements of road width and geometry and various data of road equipment are achieved by combining stereo photogrammetry and GPS technology. Applied techniques and procedures ensure georeferenced data in relatively short time countrywide. Capturing road data with the system offers quick and reliable method for updating road databases.

1. Introduction

Georeferenced measurements of road geometry and road objects present a new concept in generation of road databases. Road databases in the past were linked into object space through a chainage system. Organisation of road data based upon length measurements from the appointed node did not connect database records into the state coordinate system. Data not connected into the coordinate system present obstacle in efficient road data management and make them impossible to link into GIS platforms. It is also impossible to include these data into modern navigation systems such as GPS technology. Therefore georeferenced data are required. Georeferenced data present state of the art in the cost efficient road data management. They are accessible directly in the state coordinate system and therefore easily connected into existing geospatial databases. An application of georeferenced data also offers further analyses in GIS environment. The realisation of such GIS in road management is influenced by many data acquisition problems. Capturing up to date road data requires a time-consuming fieldwork especially if data is needed for larger area.

A possible solution offers integration of video technique with integrated GPS/INS system. Inertial navigation system is electronic system that continuously controls position and acceleration of an object and collects navigational data without connection to the base station. Data capture is performed by means of mobile unit with mounted two digital video cameras and navigation subsystem (GPS). Integrated GPS/INS systems present most recent solution in geolocation acquisition but this is quite expensive technology. We decided to choose a low cost variant that still assures accuracy in our framework. It was used a combination of digital magnetic compass, an inclinometer and an odometer instead of expensive INS sensors.

2. Design of mobile mapping system VideoCar

The mobile mapping system VideoCar integrates vehicle, video cameras, a GPS receiver, an odometer and digital compass module. The Global positioning system determines the trajectory of the vehicle that approximates the centre of the road. The loss of GPS signal is overcame by alternative positioning system by means of digital compass and odometer measurements. The position data and the digital image records are synchronised in the GPS time frame to enable georeferencing of the captured imagery. Accurate georeferenced measurements of road width and geometry of all other objects on and beside road are achieved by digital stereo photogrammetry techniques.

Figure 1: Mobile unit with mounted sensors

2.1. Video system

Video system consists of two digital video cameras with mounted wide converter to achieve larger field of sight. Video cameras are placed in special waterproof cases mounted on the top of the vehicle. Both of the cameras are linked to video port on computer to control camera operation and image capturing. Images were grabbed with 25 frames/second on miniDV media.

From video frames it is possible to acquire semantic and metric data. To assure quality of metric data video camera must be calibrated. Camera calibration was carried out in two steps. In the first step only original camera lens were calibrated. In the second step there was mounted wide converter in front of original camera lens. For calibration field it was used the frontage of nearby hall with lot of precise constructed mesh of plate holders. There were taken 10 video snapshots of calibration filed from 10 different observing points. Image measurements for each plate holder on ten images were then introduced into computation of camera auto calibration procedure in the software package BINGO-F. Results of camera calibration are focus and distortion of the lens and principal point of the camera. To avoid problems with uncertainty of a pixel size it was used 1 pixel as an unit in all computations.

Step	Focus	Principal point	Distortion (max. value)
Cam1	850.98 (±0.78)	5.89, 6.21	5.55
Cam 2	851.17 (±0.70)	3.49, 0.52	5.05
Cam1 (wc)	573.05 (± 0.41)	0.63, 3.60	16.99
Cam2 (wc)	571.48 (± 0.44)	0.81, 0.88	16.61

Table 1: Results of camera auto calibration; all values are given in pixels

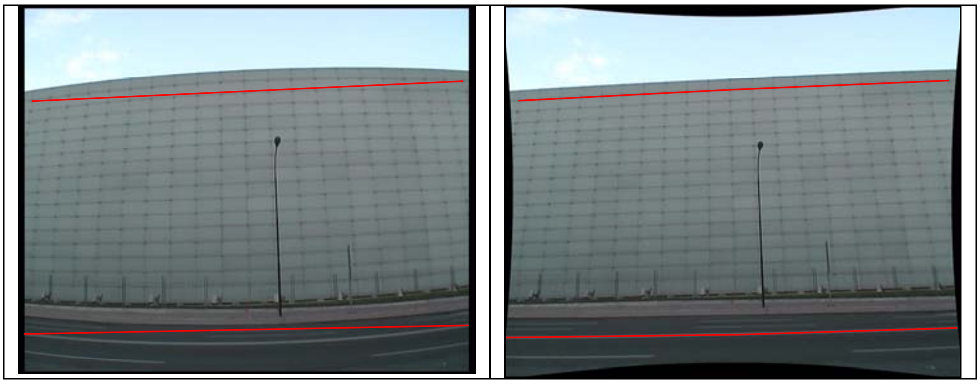

Figure 2: Calibration for image perspective and distortion

With known parameters of video camera it is possible to resample images for distortion and perspective.

2.2. Vehicle georeferencing

The main tool for vehicle georeferencing was the GPS system. During the survey it is impossible to ensure GPS signal without interruption due to the configuration of satellites, terrain and obstacles. An alternative navigation system had to be applied to avoid gaps from GPS signals. The alternative navigation system consists of angular sensors (heading, pitch, and roll) and odometer. Angular sensors are combined in specially designed digital module. Digital module consists of three magnetoresistive magnetic sensors and a liquid filled two-axis tilt sensor to produce tilt compensated heading data.

Design of used compass module ensures precise heading measurements up to 40 degrees. Digital magnetic compass is very sensitive on any disturbances of magnetic field. All magnetic compasses have to be calibrated in order to compensate for magnetic fields other than the earth's field components to get accurate heading. These additional magnetic fields are generated by the host and therefore depend on the compass mounting location. By performing a simple procedure, the digital compass module can compensate for steady, static magnetic fields known as hard iron fields. Field components found after a calibration are only valid for the particular orientation and location of the compass. A re-calibration is necessary after a relocation of the compass or if the platform has changed its magnetic character.

Compass calibration is performed by following a calibration procedure specified by the manufacturer. During this procedure the compass collects data required for the compensation algorithms. The goal of the calibration procedure is to sample the magnetic field components for many possible orientations of the host system. Rotating the host system through 360 degrees or driving in a circle (in the case of a vehicle) will enable the compass to sample its magnetic environment.

Odometer measurements are carried out with frequency 13 Hz. This is direct measurement of velocity with continuous and accurate data. Velocities derived form GPS system are compared with filtered velocities from odometer. GPS velocities that differ from odometer velocities more than 0.5 m/s are eliminated in the further procedure of odometer calibration. Velocity differences more than 0.5 m/s (1.8 km/h) could indicate blunders in the GPS data. With the rest of the data we can compute scale factor for the odometer to correct measured distances. Scale factor for odometer used in the system was 0.998.

GPS data and data from odometer are independently captured. We wanted to adjust all measurements to reference GPS time. Considering the analysis of captured data we figured out that times that used in GPS and odometer don't run with the same speed. Due to the mentioned facts both measurements have to be synchronized. Measurements are synchronized by the comparison of the direct measured velocity from odometer and computed velocity form GPS data. Identical time points in both systems are determined on the velocity chart. These points are called synchronisers. Synchronisers are used to determine conversion function between time systems and can be expressed in linear form:

$$T_{GPS} = T_{ODO} \cdot k + n \quad (1)$$

Where T_{GPS} is GPS time, T_{ODO} time of odometer, k represents difference in time scale and n represents time shift between the time systems.

In table 2 are example data which represent 27 synchronisers. That means that we have 27 equations and two unknowns. GPS time is adequate to UTC time and independent of our measurements. Time of odometer starts with beginning of the working session. Longer is the working session larger are differences between times of both systems. For the example data is mean difference between times 0.6 seconds per hour. Calculated equation according to least squares adjustment can be now written as:

$$T_{GPS} = T_{ODO} \cdot 0.99983005 + 25003.172 \quad (2)$$

Accuracy of the time synchronisation is 0.1 of a second.

Id	GPS Time	Odo Time	GPS Time Comp.	Diff.
1	08:29:18.000	00:00:57.200	08:29:18.031	-0.031
2	08:45:18.000	00:16:57.200	08:45:17.873	0.127
3	09:06:18.000	00:37:57.600	09:06:18.066	-0.066
4	09:14:18.000	00:45:57.800	09:14:18.187	-0.187
5	09:41:18.000	01:12:57.800	09:41:17.921	0.079
6	09:59:48.000	01:31:28.200	09:59:48.139	-0.139
7	10:18:18.000	01:49:58.400	10:18:18.157	-0.157
8	10:44:18.000	02:15:58.400	10:44:17.901	0.099
9	10:55:48.000	02:27:28.400	10:55:47.787	0.213
10	11:00:48.000	02:32:28.600	11:00:47.938	0.062
11	11:19:18.000	02:50:58.800	11:19:17.956	0.044
12	11:30:18.000	03:01:59.000	11:30:18.047	-0.047
13	11:51:48.000	03:23:29.200	11:51:48.036	-0.036
14	12:00:18.000	03:31:59.200	12:00:17.952	0.048
15	12:20:18.000	03:51:59.400	12:20:17.955	0.045
16	12:43:48.000	04:15:29.600	12:43:47.923	0.077
17	12:59:48.000	04:31:29.800	12:59:47.966	0.034
18	13:15:18.000	04:47:00.000	13:15:18.013	-0.013
19	13:30:48.000	05:02:30.200	13:30:48.060	-0.060
20	13:48:18.000	05:20:00.200	13:48:17.888	0.112
21	13:52:18.000	05:24:00.400	13:52:18.049	-0.049
22	14:01:18.000	05:33:00.400	14:01:17.960	0.040
23	14:16:18.000	05:48:00.600	14:16:18.012	-0.012
24	14:33:48.000	06:05:30.800	14:33:48.040	-0.040
25	14:42:48.000	06:14:30.800	14:42:47.951	0.049
26	14:53:48.000	06:25:31.200	14:53:48.243	-0.243
27	15:03:18.000	06:35:01.000	15:03:17.949	0.051

Table 2: Time data

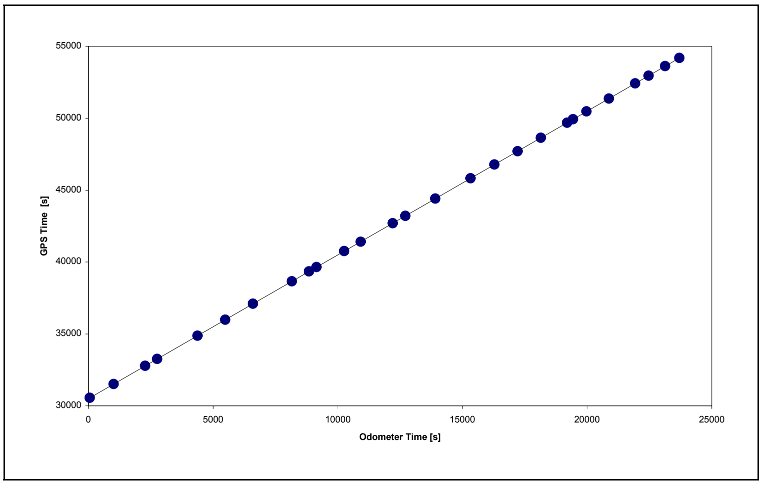

Figure 3: Time of odometer vs. GPS time

If we are synchronizing measurements manually, the achieved accuracy of synchronisation can be about 0.1 to 0.2 of a second. The results of synchronisation could be improved by implementation of automatic procedure that would compare gradients velocities.

2.3. Software

Due to the specific needs of the project realisation there was no proper software to fit our demands. For the exterior orientation of the video images we developed program Gladiator (Figure 4). The main tasks of the software are:

- Checking and managing trajectory
- Synchronisation of the GPS measurements with angular and odometer measurements
- Synchronisation of the GPS measurements and video images
- Calculating trajectory from angular and length measurements

Video images were processed in the program VideoCar (Figure 5). The main tasks of this program are:

- Stereo and mono image data acquisition from video images
- Road width measurements of
- Object attributing
- Database creation
- Preparation of report forms

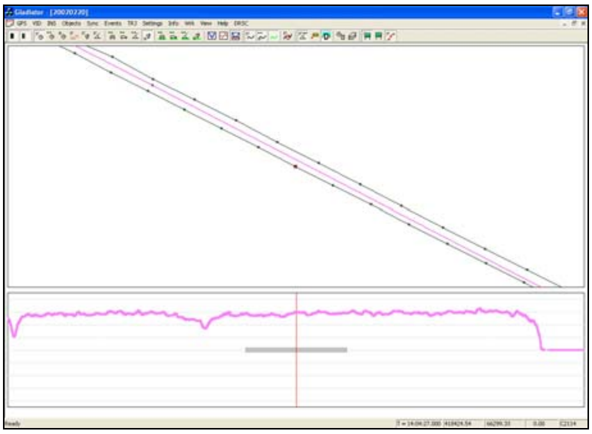

Figure 4: Data processing in Gladiator

Figure 5: Video processing in VideoCar

2.4. Object georeferencing

Input data for data processing are field measurements:

- Video images
- Trajectory
- Camera calibration data

The first step in data processing is time synchronisation of video images to reference time of the GPS system. Both data are captured independent. GPS measurements are captured in 1 second period while the video time unit lasts 1/25 of a second. We begin with initial synchronisation, which is made manually. We compare video tape and GPS data. Most useful moments are those where the vehicle is beginning to move or where it is stopping. Useful moments are also when the vehicle is in sharp turns. For example: we set the first frame on video tape where the vehicle is starting to move or the frame when the vehicle has stopped. Then we check GPS data to find moments where the vehicle is still moving or not. On the basis of these two moments we can synchronise both times accurately from 1 to 2 seconds. Initial synchronisation is used to obtain data that is needed to calculate exact synchronisation.

When we have initial synchronisation for GPS and video time, we can make exact synchronisation. We need fixed point, which can have also known spatial coordinates. Coordinates of fixed point can be obtained by intersecting spatial lines constructed from more consecutive video frames (figure 7). In the case where we have fixed point with known coordinates we can determine the best fitting of the computed coordinates with known ones by the variation of the time shift between the GPS time and video time. Variation of the time shift is carried out from the moment determined in the initial synchronization considering 1 second ahead and 1 second before. We obtain the moment of exact synchronisation when the difference between given and computed coordinates is minimal. In figure 6 we can see that the coordinate differences for given measurements are minimal at time shift –0.2 of a second. This value is added to the time of initial synchronisation. When we don’t have known coordinates of the fixed point, we are seeking for the best accuracy of computed coordinate by variation of time shift.

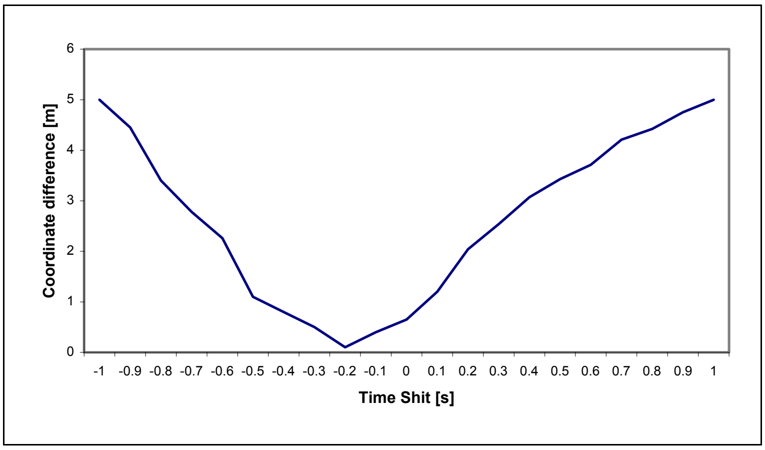

Figure 6: Exact synchronisation

Image measurements are carried out for all objects that we would like to georeference. Results of image measurements are image coordinates. Combining the image measurements with georeferenced video images we get input data for last step in object georeferencing.

In case of stereo image measurements, space coordinates of objects are computed with a known algorithm for stereo photogrammetric resection. The required input data for this algorithm are relative orientation of video cameras and their position in coordinate system of reference (state coordinate system). Space coordinates of objects can also be determined in single image restitution. In this case, image coordinates of the selected object are measured in several consecutive video frames. From the object in the reference coordinate system through the camera focus is constructed a space line for each event of the image measurement. Bundle of space lines intersects on the selected object. Intersection of these lines determines space coordinates of the object.

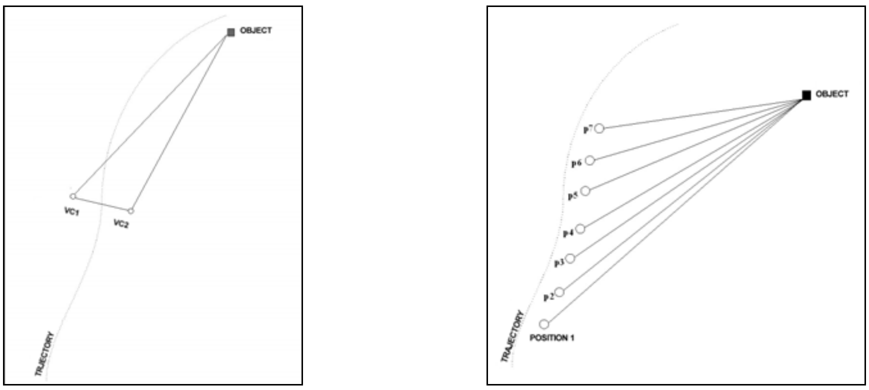

Figure 7: Stereo and multi-single image restitution

2.5. Road width measurements

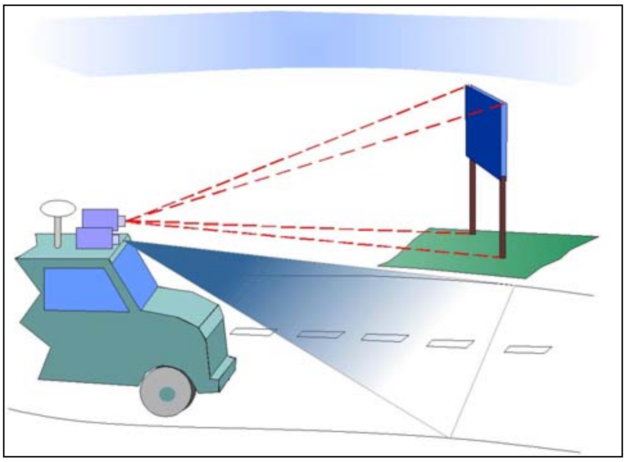

Figure 8: Road width measurement concept

The road width is determined with intersection of plane constructed through camera focus and plane on the road level. For accurate measurements of the road width the lens distortion acquired in camera calibration procedure has to be known. The main problem in measuring road width in this procedure is unambiguously defining the roadside. It often appears that road does not have any side marks or they are indefinable.

3. Practical experiences with the system

Experiences with the system will be shortly briefed from project carried out in co-operation with Directorate of the Republic of Slovenia for Roads. Mobile mapping system VideoCar was used in extensive countrywide project in Slovenia. The aim of the project was to obtain the geolocation and geometry of the tourist signalisation on the state roads.

3.1. Route planning

Daily routes had to be carefully planned in optimal loops around the GPS reference points. Reference points were selected on chosen locations to achieve baselines shorter than 50 km. For the project, there were 43 planned routes. The average length of the route was about 134 km, ranging particular routes from 94 km to 163 km. The length of the route was planned taking into account the configuration of the terrain and the day length.

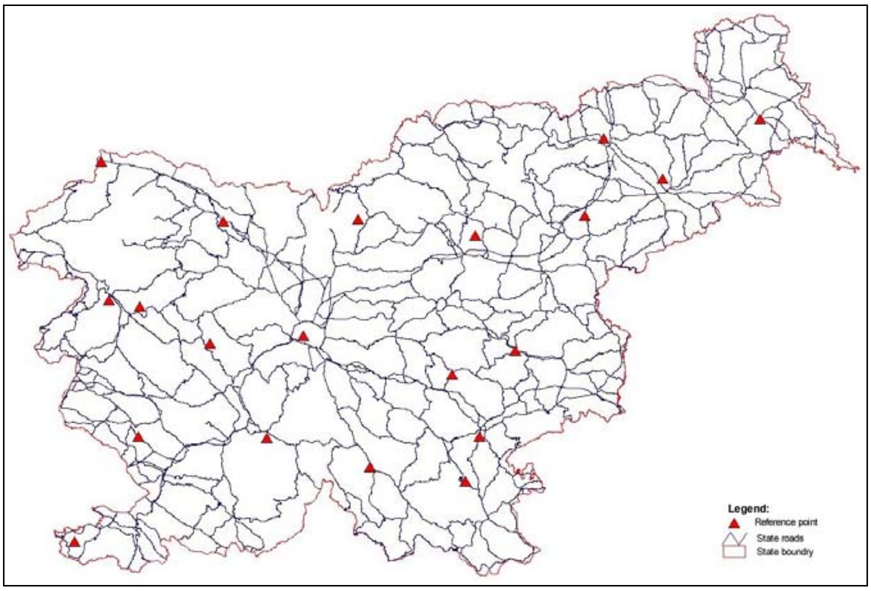

Figure 9: Slovenian state roads and selected reference points

3.2. GPS survey

Selected GPS processing method was relative kinematic with post processing. GPS data registration interval was reduced to 1 second to assure enough quality data for image georeferencing. Average speeds of surveying vehicle were ranged from 39 km/h to 51 km/h. Vehicle's speed was adjusted to temporary road and traffic conditions. In the optimal conditions (straight road, open sky) maximal allowed speed was 60 km/h. Proper velocity reduction was applied in less favourable conditions (winding road in the woods) where GPS signal interruption appeared. The vehicle was stopped after longer period without GPS signal. During the stoppage there were usually enough data collected to acquire position of the vehicle.

3.3. Acquiring data from video images

Prerequisite for quality data acquisition from video images is calibration of video cameras. It is also important that the survey is carried out in good weather conditions: no rainfall, no fog, dry roads, and position of the sun far above the horizon. Experiences, gained during the project, pointed out that the best conditions are in cloudy days without rain when light is diffuse. Images taken at these conditions are slightly less contrast but there is no harmful effect of direct sunlight.

4. Results

During the project, all state roads were passed in total length of 5896 km (11792 km in both directions) in period of 5 months. Eventually there were only 47 days with good weather conditions. On videotape was recorded about 310 hours of road data. Analysing the results after GPS data processing, we can say that for 85% of roads sub meter accuracy of road centreline was achieved during the good GPS signal. Using the alternative positioning system, the accuracy of centreline was slightly reduced. The geolocation accuracy of the tourist signalisation was approximately 1m. The quality and reliability of the results were approved by superimposition of the data on digital ortophotos in scale 1:5000 and an independent control survey.

From video images 4711 tourist information signs were captured. Each sign was georeferenced. On each sign were measured the size of the sign, the length from the roadside and identified the contents of the sign. It was also identified and measured all road contractions. Geometry of road width and tourist signalisation was measured within 5 cm accuracy.

5. Further possibilities of the system

The system was developed for concrete project and produced satisfying results. On the bases of gained experiences, we can suggest that this technology could be accepted on many other tasks in the field of road infrastructure registration:

- Updating database of state roads centreline
- Registration of road centreline
- Setting the attributes on road categorisation
- Registration and categorisation of junctions
- Cadastre establishment of horizontal and vertical road signalisation
- Registration and analyse of road objects
- Visual control of road surface

State road centrelines were acquired with the GPS system in ETRS89 coordinate system. All Slovenian topographic maps, except the latest military maps, are referenced in Slovenian state coordinate system. Connecting road data to the existing topographic maps or their application in GPS navigation is not trivial. Road data acquired with VideoCar system can be easily transformed into vector road network map in ETRS89 coordinate system. Vector roadmap is essential for modern navigation systems.

Applying the technology is possible to use automatic feature extraction of traffic signs and attribution of particular road sections. With these data, we can create database of speed limits, obstacles on road, road contractions, road orientation and road categorisation. This database could be used in precise route planning and assistance in GPS navigation. Applicability of the system could be also approved in traffic security improvement. Slightly modified navigation system connected to road database (mentioned above) could warn users exceeding speed limits or in the near future even automatically reduce vehicle's speed.

Video images do not contain only metric data, but they are also full of semantic data. It is possible to capture data about road attrition, condition of road and road objects. This information could be analysed and used to improve traffic safety.

6. Conclusion

Temporary state and possibilities of the system ensure above mentioned results and accuracy. Further possibilities to improve the mapping system are in automating time synchronisation of measurements and optimisation of synchronising algorithms. Improvement of georeferencing accuracy is also possible by integrating inertial measurement systems using sophisticated filters such us Kalman filter. This is next step to be done.

Bibliography

[1] Fras Zmago, Gvozdanović Tomaž, Bovha Dominik, Brilej Marjetka, Lebar Lidija, Krivec Mihaela, Pollak David, Mahnič Marko, Ranfl Uroš, Smole Domen, 2003. Project Data acquisition of turist and other road signalisation – final report.

[2] Fras Zmago, Gvozdanović Tomaž, Bovha Dominik, Brilej Marjetka, Lebar Lidija, Krivec Mihaela, Pollak David, Mahnič Marko, Ranfl Uroš, Smole Domen, 2002. Project Video almanac of road 2002 – final report.

[3] Fras Zmago, Gvozdanović Tomaž, Bovha Dominik, Brilej Marjetka, Lebar Lidija, Krivec Mihaela, Pollak David, Mahnič Marko, Ranfl Uroš, Smole Domen, 2003. Project Data acquisition of road crossings – intermediate report.

[4] Caruso Michael J., 1997. Applications of Magnetoresistive Sensors in Navigation Systems, Honeywell Inc. Technical Articles. http://www.ssec.honeywell.com/magnetic/datasheets/sae.pdf

[5] Kozmus Klemen, 2001. *Inertial systems in geodesy*.
http://www.fgg.uni-lj.si/~/mkuhar/Zalozba/INS_v_geod_Kozmus.pdf