MAPPING AND 3D MODELLING OF URBAN ENVIRONMENT BASED ON LIDAR, GPS/IMU AND IMAGE DATA

Krzysztof Gajdamowicz, Ph.D., Daniel Öhman, Milan Horemuz, Ph.D.
Visimind AB, Södra Långgatan 23, 169 59 Stockholm, Sweden
tel +46 8 59495549
info@visimind.se

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ABSTRACT:

There are several ways to reconstruct the 3D coordinates in object space. A number of methods estimate the 3D information using active sensors such as laser scanners, rangefinders or radars. Other methods use passive sensors and image analysis. Mobile Mapping Systems (MMS) approach the problem of 3D mapping by mixing passive and active sensors with direct or indirect methods for geo-referencing. Unfortunately direct geo-referencing is not possible in some areas of urban or forest environment. This paper presents approach of direct geo-referencing based on inertial navigation system supported by image and range observations. Camera observations of points with known object coordinates provide positional as well as attitude support to IMU navigation. If common object points are visible on more than one image, it is possible to perform a bundle adjustment, where both camera and object positions can be computed. The main problem with bundle adjustment is generation of approximate coordinates. In the described approach the laser scanner observations were used. The position and orientation of laser scanner was determined by IMU supported by GPS. GPS usually has many outages in urban areas, therefore GPS/IMU combination does not provide position and orientation of laser scanner with sufficient precision. But this precision usually suffices for the generation of approximate coordinates for the bundle adjustment. This paper presents the preliminary results, outlines the algorithms and addresses the difficulties related to scene reconstruction, as well as image and inertial data analysis.

1 INTRODUCTION

The original principle of the land based Mobile Mapping System (MMS) is based on the geo-referencing of a photogrammetric model by GPS, INS or IMU and the odometer. In cases where the absolute accuracy less than 0,5 metre is required the geo-referencing is done mainly based on GPS where the orientation of the MMS is gained from INS or IMU sensor. The odometer is used just for detection of places for Zero Velocity Update, generation of the trigging pulse for the image exposure or for the measurement of the travelled distance. This concept has several well known limitations. In urban, forest or other areas where the GPS signal is blocked direct positioning can not be obtain. Typically in such cases the INS is used. INS delivers high precision information about orientation of the platform but due to gyros drift the angular accuracy becomes weaker over the time and both orientation and positioning can not be performed correctly. Several research groups tried to overcome this problem by integrating the GPS with INS using Kalman filter (Bossler J., Goad, C., Johanson P., Novak K., 1991, Schwarz K. P., Martell H.E., 1992; Schwarz K. P, El-Sheimy N., 1995) others, mainly in case of air-borne systems, applied block triangulation as the support to integrated GPS/INS (Skaloud, Schwarz 1998; Colomina, 1999; Abdullah, Tuttle 1999; Burman 2000; Heipke et al 2000).

In 1999, the Dept. of Infrastructure, The Royal Institute of Technology, Sweden in cooperation with Visimind formulated a research project focusing on methods of mapping of the urban, indoor and other environment based on image analysis supported by inertial information only. The project was funded by the Swedish Research Council. In year 2004 the project was completed and the results were presented in Kumming on MMT symposium. The research was divided in two steps. In the first step the hardware module of MMS called TN-K (Inertial Unit - Camera) was created. The second step of the project focused on the development and tests of the methods for automated 3D mapping based on image and IMU data.

The research presented in this paper extends the previously presented TN-K concept (Gajdamowicz at al 2004) by integration of the IMU/Camara observations together with rage information obtained from laser scanner (LiDAR).

The results outlined in this paper show how the feature extraction and tracking, laser and IMU data combined in extended Kalman filter improves the geo-referencing and allows to model 3D scene in places where GPS is not available.

2 VISIMIND MMS – HARDWARE, DATA ACQUISITION AND DATA PROCESSING MODULES

The hardware module for this project consists of the following integrated units:

- IMU from Imar GMBH.,
- GPS/GLONASS from Topcon
- Colour progressive scan digital cameras from SONY (at least 6 cameras with resolution from 2 to 4 MPixel)
- PC and power supply system
- software module for data acquisition (DAM)
- Laser scanner (Leica, Reigl)

The data acquisition software of Visiminds MMS was modified in order to steer and control the data flow.

Figure 1. Visimind MMS - the data acquisition hardware, ©Visimind 2007

Two software modules were developed within the project: Data Acquisition Module (DAM) and Data Processing Module (DPM). The DAM software synchronizes and records the data from IMU, GPS, cameras and laser scanner to hard disk. The system is calibrated internally, relatively and externally. The collected stereo images, image sequences and laser range data allow for surveying of any point visible in the images or in laser data. The measured coordinates are presented in a global coordinate system. The front and rear stereo cameras are used mainly for acquisition of the features and objects along the roads, while the mono side cameras collect image sequences with overlap of 90 % for surveying of building facades or side walks. The scanners in Visimind system scan from 10 000 points per second and 60° opening angle to 500 000 points per second and with 340° opening angle. Combined image and laser data allows for documentation and 3D surveying of surroundings of the van.

The data acquisition is done continuously from all sensors. The working frequency of image acquisition is from 3 to 6 images per second from all cameras. The range of the scanners is up to 400 m. The acquisition has no speed limitation and it follows the traffic. The data can be easily acquired on highways as well in urban areas.

The data is processed in several steps with help of Post Processing Module (PPM) and also using standard GPS data processing software such as Pinacle. The results are visualized by DPM software.

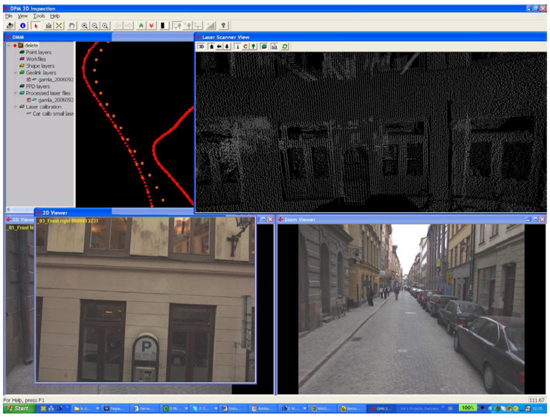

Figure 2. DPM software and acquisition of building facades in Stockholm Old Town. ©Visimind 2007

3 MAPPING IN URBAN ENVIRONMENT – LASER AND CAMERA SUPPORTED POSITIONING AND NAVIGATION

Visimind performs several thousand km of mapping yearly. Parts of the projects are performed in very hard conditions, i.e. where GPS signal is not available. For this purpose Visimind has develop an algorithm and methodology that allows positioning and navigating using support form camera and laser scanner observations. Several works was already presented on the topic related to the combination of photogrammetry, GPS and bundle adjustment such as Ackerman 1992, Brown 1972 or Cameron & El-Sheimy 2005. This paper outlines an algorithm where bundle adjustment, camera and laser scanner observations along with Kalman filtered GPS/IMU are used to overcome loss of lock and to create the data that will allow for crating the architectural drawings of the façades in scale 1/100.

The procedure to overcome GPS gaps and to calculate global coordinates of required features consists of several steps.

Step 1. Calculation of approximate coordinates of the sensors, in particular the coordinates of the camera and the laser scanner based on GPS/IMU integration.

The GPS and IMU data is integrated in PPM with help of Kalman filter yielding optimum estimate of position and orientation of the platform.. By doing so each laser scanned point gets the approximate coordinates in global frame. We consider these coordinates as approximate because of low quality or no GPS positions are available.

Step 2. Feature extraction and tracking.

Extraction of image coordinates of features or objects visible in the image sequence consists of three basic steps:

1) Feature extraction based on Harris operator.
2) Tracking of the extracted features based on Lucas Kanade Feature Tracker (Lucas B., Kanade T., 1981; Tomasi C, Kanade T, 1991.) implemented on image pyramids (Bouguet J-Y, 2000).
3) Validation of the extracted features, adding and tracking of new features.

The process of feature extraction ends with a list of the tracked features and their image coordinates in the image sequence.

Step 3. Calculation of the approximate coordinates of the tracked features.

In this step we find the relation between the image coordinates of features tracked in image sequences and their coordinates in global frame. This process assumes that the relative orientation and offset between the camera and the laser scanner is known. Using the estimated position and orientation of the camera, the directions (unit vectors) between the camera origin and the tracked features expressed in the global coordinate system can be computed. The approximate coordinates of the tracked features are computed as intersection of these directions with the laser point cloud.

Step 4. Bundle adjustment – calculation of corrected positions of the camera and object coordinates.

Here we use the image coordinates of the tracked features as observables for the least squares adjustment, in which we estimate the camera position and orientation for each image and the coordinates of the object points. This adjustment is run as minimum constraint adjustment, or, if available, we introduce constraints using known geometry of the features. For example, the points of the window corners should have the same heights or the approximate object coordinates computed when GPS fixed solution was available obtain higher weight. This process yields corrected coordinates of the features that are tracked in images expressed in the global frame and corrected positions and orientations of the camera.

Step 5. Calculation of corrected position and orientation of the platform and computation of final laser point cloud

Here we run the same Kalman filter as in Step 1, but we use also the camera observations of the tracked features to support the inertial navigation. The object coordinates of the features computed in Step 4 are considered as fixed. This gives us precise platform position and orientation and hence precise coordinates of the laser point cloud.

4 TEST RESULTS

For the purpose of evaluation of the algorithm several tests were performed. Visimind together with the Royal Institute of Technology, Division Geodesy has established a test field in central part of Stockholm in area with good and bad visibility regarding GPS, see Fig 3.

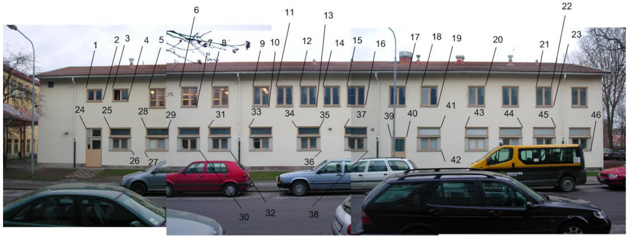

Figure 3. The test field with control points.

The test field consisting of 28 control points. was measured with total station with accuracy of 5 mm. The same area was scanned also stationary, using Leica HDS 4500 scanner - see Fig 4. The RMS between surveyed and scanned points was 0.011 m in all coordinates.

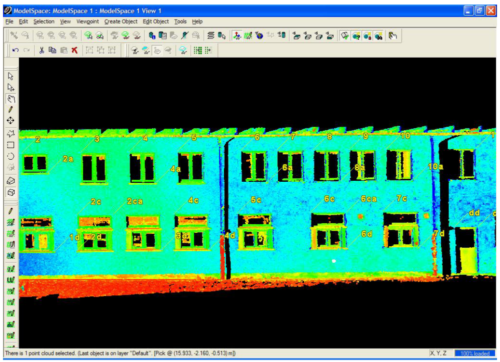

Figure 4. Scanned test area with HDS 4500.

The Visimind MMS was run along the test field. The data presented in Fig 5. has no correct GPS information and the point cloud calculated after Step 1 was shifted from the referenced values, see Tab 1.

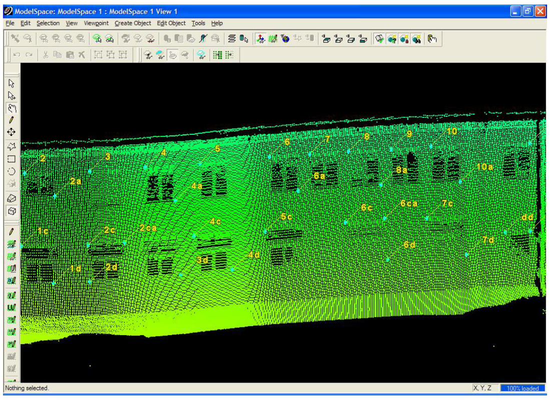

Figure 5. Point cloud of the test area after Step 1.

Then the algorithm presented in Section 3 was applied. The approximated global coordinates of the points calculated with weak GPS data were adjusted using tracked futures, see Fig 6. It is important to mention that no reference coordinates of known points were included into this process; only IMU, laser and camera observations.

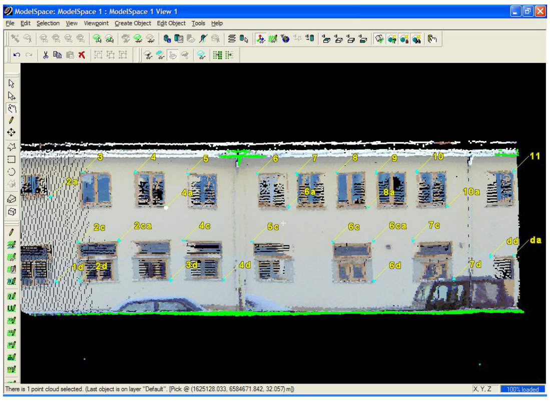

Figure 6. Corrected model, the final result.

The results presented in Tab 1. shows the RMS values of coordinates before and after correction.

Table 1. RMS values of the differences between coordinates of reference control points and coordinates of control points surveyed from not corrected and corrected data

N=28 control points /RMS [m]	**RMS (X)**	**RMS (Y)**	**RMS (Z)**
Not corrected data (Step 1)	0,107	0,109	0,067
Corrected data (Step 4 and 5)	0,094	0,063	0,038

5 SUMMARY

The results obtained during the project shows that a few seconds gaps in GPS data can be overcome using presented algorithm. Furthermore tests shows that by including into bundle adjustment several known coordinates of the control points improves the results and allows for longer runs without GPS, see Fig 7.

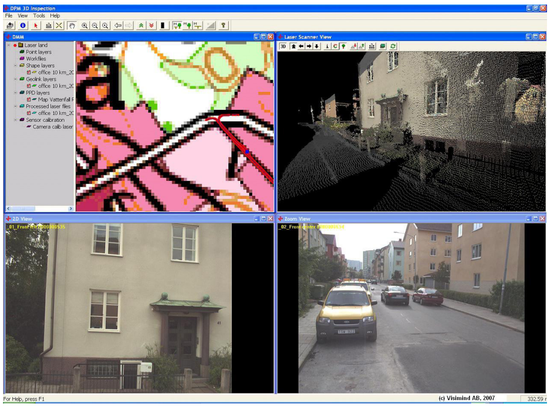

Figure 7. DPM software and acquisition of building facades in Solna city. ©Visimind 2007

6 ACKNOWLEDGMENTS

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