

A MODEL BASED APPROACH FOR ORIENTATION IN URBAN ENVIRONMENTS

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ABSTRACT:

At the Institute for Photogrammetry (ifp), Stuttgart University, current research aims at the development of tools and applications for Location Based Services (LBS). As location based access on information is a key parameter of these applications, the current user's position and orientation is essential for information access. Usually, human beings navigate and locate themselves by integrating viewpoint information (landmarks) into a coherent mental representation of the traversed environment. In urban environments with unknown, difficult and complex building structures natural orientation fails very often, because the navigator's viewpoint does not encompass the environment in its totality. Thus, intuitive automatic positioning and navigation becomes necessary. Usually GPS is used for positioning, but in urban areas GPS is jammed by multipath effects and signal loss, compasses suffer by electro magnetic fields. As pedestrians intuitively use viewpoint information to locate themselves, the idea is to use the surrounding objects (buildings) as landmarks to automate this process. In this paper an approach will be presented which uses visual information (images) collected by a digital camera, 3D city models and photogrammetric methods to provide improved orientation information in urban environments. The principle of the process for positioning by viewpoint information is the overlay of a 3D city model to the corresponding primitives in the real world. The end result of this overlay process is the accurate determination of the actual position and orientation of the user. Within this paper our approach for positioning with images will be described in more detail pointing out the whole process as well as aspects for automation.

KURZFASUNG:

Gegenwärtige Forschungsarbeiten am Institut für Photogrammetrie der Universität Stuttgart, zielen darauf ab, verschiedene Funktionalitäten für Location Based Services (LBS) bereitzustellen. Die Hauptfunktionalität solcher Dienste ist der ortsbasierte Zugriff auf Informationen. Aus diesem Grund ist die gegenwärtige Position eines mobilen Nutzers eine grundlegende Information. Üblicherweise bestimmt ein Mensch seine Position, indem er markante Objekte (Landmarken) visuell erkennt und diese einer vorhandenen, mentalen Karte zuordnet. Innerhalb einer komplexen und unbekannt, städtischen Umgebung versagt diese Art der Orientierung in der Regel, da der mobile Nutzer über keine mentale Karte der Umgebung verfügt. Vielmehr müsste diese Karte erst antrainiert werden. Eine intuitive und automatische Positionierung und Navigation kann hier hilfreich sein. Vielfach wird GPS zur Positionierung verwendet, dessen Empfang aber innerhalb städtischen Umgebungen durch Multipatheffekte und abreißende Signale gestört wird, digitale Kompassen zur Bestimmung der Orientierungsparameter werden dagegen durch elektromagnetische Felder gestört und sind auch nur begrenzt einsetzbar. Da der Mensch üblicherweise visuelle Information für seine Lokalisierung und Navigation verwendet ist die Idee, umgebende Objekte (Gebäude) als Landmarken zu verwenden. Nachfolgend wird ein Verfahren vorgestellt, dass Bilder (erzeugt von einer digitalen Kamera) in Kombination mit einem 3D Stadtmodell verwendet, um die äußere Orientierung mittels photogrammetrischer Methoden zu ermitteln. Das Prinzip dabei ist die Überlagerung von 3D Stadtmodell mit den entsprechenden Objekten der realen Umgebung. Durch einen derartigen Zuordnungsprozess kann dann die genaue Position und Orientierung eines mobilen Nutzers abgeleitet werden. Innerhalb des Papers wird das Verfahren der Positionierung mittels Bildern detaillierter beschrieben, sowie Automatisierungsansätze diskutiert.

1. INTRODUCTION

During the hype of the "new market" many scenarios were used to show the need of digital systems, which are able to support a mobile user in different situations. At this time also the idea of LBS (Location-based Services) arose and in the meantime simple LBS are offered from various sides for users of cell phones, etc. . With an emerging availability of small and powerful devices different types of applications become feasible. They enable us to access on data stored on remote systems or to stay in contact with other persons. People can get guiding support to the next restaurant, and even friend finder functionality is provided. For these applications the mobile devices (cell phones) can be localized by use of the cellular

phone network, GPS (Global Positioning System) or another type of positioning system, e.g. proprietary indoor positioning systems. For user support by overlaying the reality with additional information or for interaction with surrounding objects, these techniques are not sufficient. There are several techniques in Augmented Reality (AR) to solve these problems but often they are limited for indoors use, as the environment has to be equipped with appropriate sensor technology. Outdoors we cannot assume the same prepared environment like indoors. The approach being developed at the Institute for Photogrammetry therefore takes into account a model of the environment to support the process.

1.1 Location aware applications

If we have a closer look on the market we will notice that there are several simple information systems providing information dependent on the actual location. As these commercial systems are offered by different companies each system uses a proprietary data format. Access on data of different information providers and exchange are difficult.

An open platform for location aware applications can widen the possibilities, as everybody would be able to contribute information to the model. Therefore one challenge of the research within the Stuttgart University project NEXUS is the provision of such an open platform – the NEXUS system. This system relies on a model-based concept, called the NEXUS Augmented World Model (AWM) (Nicklas et al., 2001). The AWM is the base for the NEXUS system's extensibility and flexibility and it forms the interface to the applications. As it is an open platform also existing data sources like the WWW shall be integrated. This may lead to a great heterogeneity in the data. In NEXUS a federation approach is used to handle that heterogeneity, see Fig. 1.

A closer view to the object oriented AWM shows its basic idea: federation of information and representation of the real world (buildings, streets, cars,...). As example one representation of the real world could be a detailed 3D city model. For interaction with the AWM and the use of NEXUS services the architecture provides also an interface for sensor integration. Here different positioning sensors can be plugged in to provide the necessary position and orientation information to several applications.

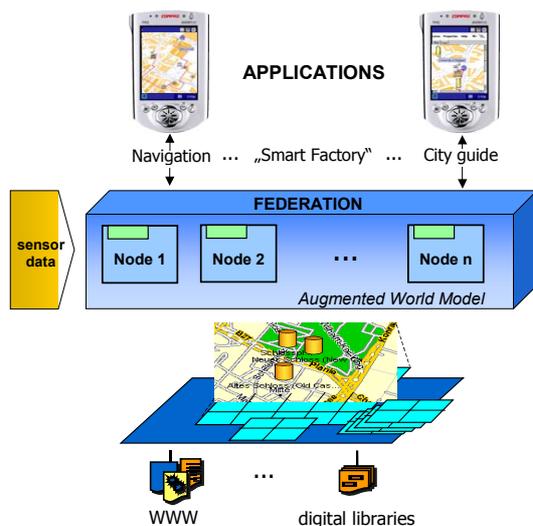


Figure1. Architecture of the NEXUS platform

2. LOCATION SENSING

2.1 Techniques for location sensing

Position information is the fundamental requirement of location aware applications. To provide this information different techniques can be used. In principle there are three methods for automatic location sensing: triangulation, proximity and scene analysis (Hightower & Borriello, 2001). Triangulation techniques use geometric properties of triangles to compute object locations. This method is divisible into the subcategories of lateration, using distance measurements, and angulation, using primarily angle measurements. As example systems like GPS or a magnetic compass use triangulation techniques. When an object is "near" a known location then this is described with

proximity. For sensing proximity there are three general approaches: (a) Detecting physical contact, (b) monitoring wireless cellular access points and (d) observing automatic ID systems.

A further method for location sensing is the scene analysis technique. Here features of an observed scene are used to conclude to the location of the observer or to the location of objects within the scene. Usually the observed scenes are simplified to obtain features that are easy to represent and compare.

The position and orientation of a user are basic information to provide high quality location based services. Azuma (Azuma et al., 1999) evaluated that all tracking systems lack accuracy or robustness. This leads to his conclusion that only a combination of different technologies, which he call a hybrid tracking system, should be used. Several systems are using GPS and additional devices to track the orientation. But often the existing approaches are not accurate enough for the overlay of a reconstruction of real world objects or they cannot be applied to persons walking in a city without the requirement of fixed positions where they should stand to receive information. The Touring machine of Columbia University in New York is one of the most well known information systems (Julier et al., 2000). It broadcasts information about names of the buildings, so positioning and orientation accuracy are not the most important conditions. To provide information about more specific building features the requirements on position and orientation accuracy are higher. The use of image processing techniques is a method to improve results. Beveridge (Beveridge et al., 1996) and Behringer (Behringer, 1999) used horizon shapes extracted from a visual scene to look up the observer's location from a prebuilt dataset. In You (You et al., 1999) an augmented reality system is described which tries to correct drift errors of a gyroscope and errors of the compass using images collected by an additional camera.

Pedestrians usually use viewpoint information and landmarks (e.g. buildings) to locate themselves in a familiar environment. To facilitate the same in an unfamiliar environment an automation of this process should be provided by combining the model of the environment and surrounding objects (landmarks). In the research project NEXUS a model of the real world exists – the Augmented World Model. This model contains various information as well as a 3D representation of real world objects (e.g. buildings). On that condition we are able to integrate divers sensors and operations on these data to support pedestrian orientation and navigation.

2.2 Orientation and navigation using scene analysis

In the last years the availability of low-cost imaging devices increased. The combination of mobile computational capabilities, imaging capabilities, positioning devices and network access opens a door for novel applications. As example Augmented Reality applications in urban regions are useful to assist users and to interact with the model of the environment. Especially in NEXUS where a model of the environment exists information about objects can be provided by identifying them. In order to allow information access or to use objects as landmarks for navigation, the link between the Augmented World Model and the observed environment has to be generated. As we concentrate on image information this leads to an approach which tries to overlay the model and the corresponding primitives in the real world. Similar approaches often use a database where manually geo-referenced sequential images are registered. Then through the registered image the landmark lines are transferred on the other unregistered images

by image-to-image matching (e.g. based on straight line features) to get the accurate position and orientation for the real world images taken by the camera later. We do not use such comparison methods but a geometric 3D model of the environment, providing also 3D information about objects.

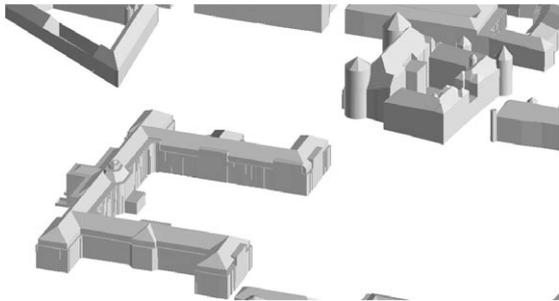


Figure 2. 3D city model (centre of the city of Stuttgart)

The basic information to provide orientation and navigation by image analysis is the availability of a suitable geometric “world model”. As example a (geo-referenced) 3D city model represents such a world model, see Figure 2. Nowadays 3D city models for large areas are easy to provide, as in the meantime automatic methods for generation of such models are available (Brenner, 2000; Wolf, 1999). For example the City Surveying Office of Stuttgart offers such a 3D model of the centre of the city for sale.

2.2.1 Feature extraction: As the principle of our method is to co-register image and model data using prominent features in the real world and the world model, suitable features must be identified in the image, by image analysis techniques. The main objects of interest within an urban environment are human made objects, e.g. buildings. If we have a closer look to these objects so the prominent features of them are texture and edges. The edges of human made objects often can be approximated by straight lines, therefore we decided to select edges as prominent features. Also objects in the 3D city model are modelled by straight lines.

For edge extraction and straight line approximation different operators are available, e.g. Burns-Algorithm (Burns, 1986), but also the Hough-Transform (Hough, 1962) is a suitable algorithm to extract straight lines. Using these algorithms we can prepare the collected data (images) and extract the necessary feature information. In Figure 3 the result of these process is displayed and the extracted straight lines are marked in red.

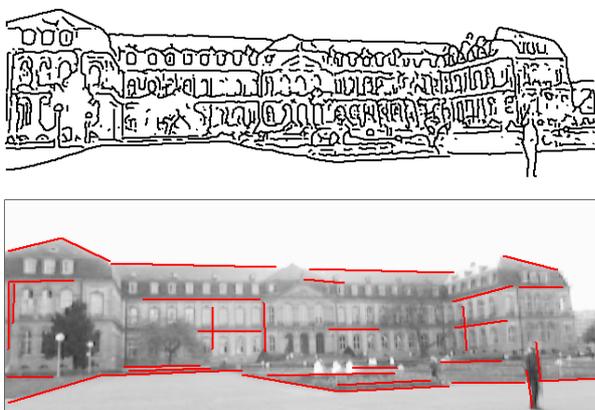


Figure 3. Feature extraction and line detection

On the one hand side the base information for our approach is provided by the straight line extraction and on the other hand side by the world model (=3D city model). The problem that occurs now is to select candidate objects within the world model for further processing. Additional information provided by simultaneous collection of image data as well as rough orientation and position information can help to identify one or a set of candidate objects. By using our prototype for direct collection of exterior orientation parameters we are able to solve this problem. The prototype integrates an image sensor (CCD camera), an orientation module for goniometry and a GPS receiver, which provides rough position information.



Figure 4. Prototype sensor

To extract required data for further processing we have to query the model for objects, which are contained in the viewing frustum of the camera and select the visible objects (see Fig. 5). The data collected by the prototype sensory can help us to extract these model data by an integrated processing of sensor and model data.

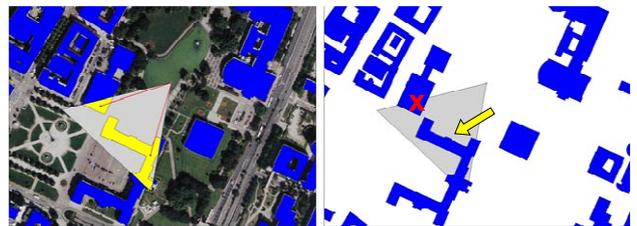


Figure 5. Extraction of visible objects

2.2.2 Feature Matching: To solve the model (Augmented World Model) to image registration problem the features of the selected and extracted 3D object model and the features extracted in the 2D image must be assigned. This is the task of determining straight lines in image and object space that are belonging together. Automatic registration of 3D models to images is a fundamental and open problem. It is difficult because it comprises two coupled problems: the correspondence and the pose problem. Each sub problem is easy to solve only if the other has been solved first. A classic approach for solving these coupled problem is the hypothesize and test approach. First a small set of image feature to model feature correspondences are hypothesized, e.g. using sensor data collected by the prototype sensor to minimize the search space. Based on the result the object’s pose is computed and the model is back projected into the image. The pose is accepted if the original and back projected image are sufficiently similar, otherwise a new hypothesis is formed and the process is repeated. As example the method of Beveridge and Riseman (Beveridge&Riseman, 1995) uses a random start local search with a hybrid pose estimation algorithm employing both full-perspective and weak-perspective camera models. To simplify the equations often linear affine approximations (weak-

perspective) of the nonlinear perspective projection are used. This is accurate if the distance of the object to the camera is small compared to the relative depth of the object features. In David et. al (David et. al., 2003) the extended SoftPOSIT algorithm for simultaneous pose and correspondence determination for the case of a 3D model and its perspective image is illustrated. The extended SoftPOSIT algorithm uses line features for the matching process. Within the algorithm an iteration is performed, where at each step the given 2D-to-3D line correspondence problem is mapped to a new correspondence problem, which depends on the current estimate of the camera pose. The algorithm is then applied to improve the estimate of the camera pose and stops if pose and correspondences converge.

2.2.3 Spatial resection for exact co-registration and georeferencing: The methods described in section 2.2.2 are able to solve the correspondence problem, but for simplification they are using a weak perspective. For exact co-registration and georeferencing a further iteration is necessary using the spatial resection approach. For this approach we assume that at least the correspondence problem between object and image features is solved.

$$Y = \alpha \cdot X + \gamma \quad Z = \beta \cdot X + \delta \quad y = \alpha \cdot x + b \quad (1)$$

$$a_x = \frac{r_{31}(Y_0 - \alpha X_0 - \gamma) + r_{21}(\delta - Z_0 + \beta X_0) - r_{11}(\alpha(\delta - Z_0) - \beta(\gamma - Y_0))}{r_{32}(-Y_0 + \alpha X_0 + \gamma) + r_{22}(Z_0 - \delta - \beta X_0) + r_{12}(\alpha(\delta - Z_0) - \beta(\gamma - Y_0))} \quad (2)$$

$$b_x = x_h \frac{r_{31}(-Y_0 + \alpha X_0 + \gamma) + r_{21}(Z_0 - \delta - X_0\beta) + r_{11}(\alpha(\delta - Z_0) - \beta(\gamma - Y_0))}{r_{32}(-Y_0 + \alpha X_0 + \gamma) + r_{22}(Z_0 - \delta - \beta X_0) + r_{12}(\alpha(\delta - Z_0) - \beta(\gamma - Y_0))} + y_h \frac{r_{33}(-Y_0 + X_0\alpha + \gamma) + r_{23}(Z_0 - \delta - X_0\beta) + r_{13}(\alpha(\delta - Z_0) - \beta(\gamma - Y_0))}{r_{32}(-Y_0 + \alpha X_0 + \gamma) + r_{22}(Z_0 - \delta - \beta X_0) + r_{12}(\alpha(\delta - Z_0) - \beta(\gamma - Y_0))} \quad (3)$$

Based on results of the feature matching process an exact co-registration of image and object space can be provided by spatial resection. The principle of this algorithm is to overlay extracted lines in the image and corresponding edges of the 3D CAD model to estimate the parameters of the exterior orientation (= position and orientation to the time of data collection). The camera parameters (x_k , y_k and c_k) in equation (3) are fix values, estimated by a separate camera calibration process. The principle of the feature based spatial resection process is illustrated in Figure 6.

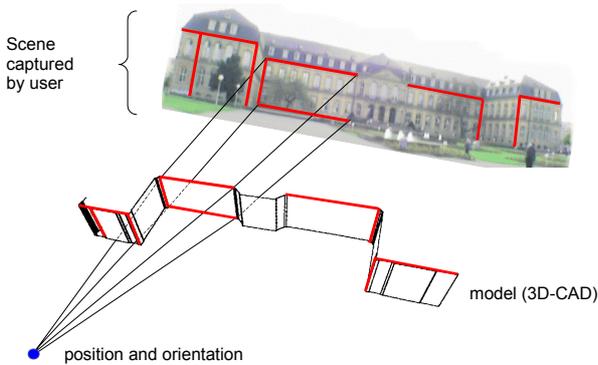


Figure 6. Principle of the feature based spatial resection

For the feature based spatial resection initially the well-known collinearity equations are utilized, e.g. (Kraus, 1996). As we are using straight lines as tie-information, the commonly used collinearity equations are modified by the parameterisations (1).

The resulting equations are shown in (2) and (3). A more detailed mathematical description of this context can be found in (Schwermann, 1995). To solve the spatial resection problem, a least squares algorithm using the Gauss-Markov-Model was implemented. Here the unknown parameters (X_0 , Y_0 , Z_0 , ω , φ , κ) are estimated and an exact co-registration of object and image space can be provided.

Up to now we assumed: (a) that the feature matching problem (between image and object space) is solved and (b) that parameters of the rough exterior orientation are available. In some circumstances it will be impossible to solve the matching problem automatically or there will be no information about the initial orientation parameters. For a semi automatic approach there exist a method to solve this problem. The collinearity equations clearly describe the mapping process of a 3D object into the image space. But in a least squares approach (as used for solving the spatial resection) the non-linear equations cannot be used without initial values. To overcome this dilemma and for estimation of rough (initial) exterior orientation parameters the feature based direct linear transformation (DLT) is usable. As the DLT is linear, the unknown parameters of the exterior orientation can be calculated directly within a least squares approach. The equations of the feature based DLT are shown in (4) and (5).

$$x = \frac{(\alpha L_1 + \beta L_2 + L_3) \cdot Z + (\gamma L_1 + \delta L_2 + L_4)}{(\alpha L_9 + \beta L_{10} + L_{11}) \cdot Z + (\gamma L_9 + \delta L_{10} + 1)} \quad (4)$$

$$y = \frac{(\alpha L_5 + \beta L_6 + L_7) \cdot Z + (\gamma L_5 + \delta L_6 + L_8)}{(\alpha L_9 + \beta L_{10} + L_{11}) \cdot Z + (\gamma L_9 + \delta L_{10} + 1)} \quad (5)$$

Using equations (4) and (5) the unknown parameters L_1 - L_{11} can be obtained by a least squares approach. This offers the possibility to derive the exterior orientation parameters (X_0 , Y_0 , Z_0 , ω , φ , κ) from the L_1 - L_{11} parameters (Krauß, 1983), which can be used as initial values for the feature based spatial resection. The solely disadvantage of the DLT method is the higher order of the unknown parameters compared to the spatial resection method. Therefore we need a higher number of observations ($n_{\text{obs}} \geq 6$) to be able to compute the eleven DLT parameters. Once the DLT is solved, the initial values for the spatial resection approach are available. To derive the orientation angles (ω , φ , κ) the rotation matrix must be set up using the parameters L_1 - L_{11} . Note here, that the least square method for computing the DLT parameters, does not automatically guarantee an orthogonal transformation matrix. A modified DLT method proposed by Hatze (Hatze, 1988) addresses this problem. In principle the postulate of an orthogonal rotation matrix should be fulfilled to guarantee a correct solution, but as we need the orientation parameters only as initial values, this postulate can be neglected if the errors are small. With this initial values we are able to compute the exterior orientation by the feature based spatial resection.

Dependent on the available initial information different approaches are possible, which are depicted in Figure 7. The trivial requirement is the availability of an image and a suitable 3D model of the environment. Then in principle two ways are possible to calculate the exterior orientation. The process can be started if information about the initial exterior orientation is available but also if this information is missing. If there is no initial information the problem can be solved by a semi-automatic approach: First of all the features must be extracted (automatic or manually), then they can be manually co-registered to the model data. After the co-registration the DLT method is applicable to calculate initial values of the exterior

orientation, which act as input data for the feature based spatial resection. The other way is to start the process if initial values are existing. In that case we have good basic information, hence we can extract the necessary features more specific. To identify the object and regions of interest for feature extraction a “General Hough Transform” is utilized. Once the regions are known and the features extracted, the spatial resection algorithm is started to compute the exterior orientation parameters.

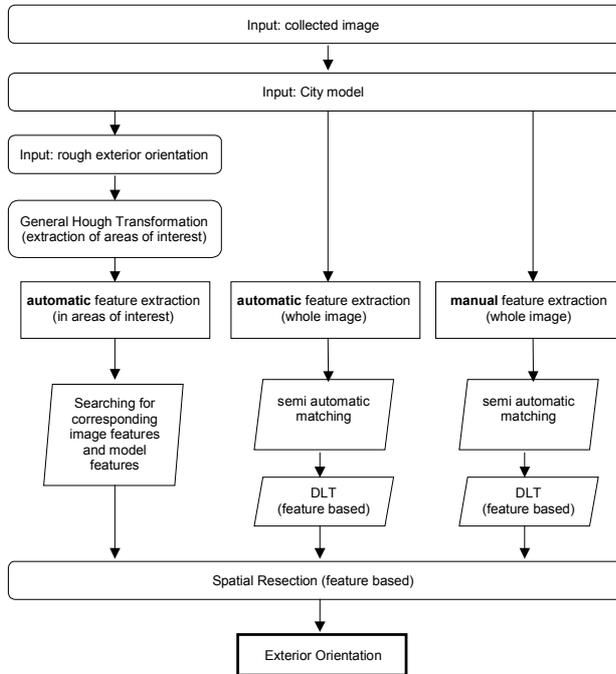


Figure 7. Process for determination of exterior orientation

3. EXPERIMENTS AND RESULTS

Several examples were chosen to investigate the feasibility of our approach. The investigations are based on a 3D CAD dataset of the city of Stuttgart provided by the City Surveying Office. This 3D CAD city model was created by manual photogrammetric stereo measurements (Wolf, 1999). In the dataset of the City Surveying Office a large amount of detail is available and its accuracy is high. Therefore we decided to use this dataset. Additionally also a synthetic dataset was prepared to be able to study the quality of the feature based method. In the synthetic dataset an ideal camera was simulated for projection of objects into image space. The advantage of the simulated dataset is that there are no distortions in the image space, which offers the possibility to study the quality of the feature based spatial resection method.

real dataset:

rough exterior orientation (collected data)			
X	910.62 m	ω	10.63°
Y	89.17 m	φ	64.7°
Z	58.15 m	κ	0.0° (predefined)

spatial resection			
	points	straight lines	differences
X	904.45 m	904.66 m	$ \Delta X $ 0.21 m
Y	72.13 m	72.41 m	$ \Delta Y $ 0.28 m
Z	52.46 m	52.28 m	$ \Delta Z $ 0.18 m

ω	9.9°	10.1°	$ \Delta\omega $	0.2°
φ	61.4°	63.0°	$ \Delta\varphi $	1.6°
κ	-2.56°	-3.4°	$ \Delta\kappa $	0.84°

Table 1. Results of the real dataset

Table 1 shows results using a real dataset and Table 2 shows result of a synthetic dataset. In the table of the real dataset the rough exterior orientation collected by the prototype sensor is displayed. These values are also used as initial values in the spatial resection process. The results displayed in both tables are created by the feature based spatial resection method as well as by a spatial resection using manually selected tie points as input data. The results of the point based method act as reference data, as this method provides the most accurate results. In the table of the synthetic dataset (Table 2) additionally the results of the DLT method are added, to show their ability for determining initial values.

synthetic dataset:

rough exterior orientation (predefined/synthetic)			
X	905.00 m	ω	10.0°
Y	72.00 m	φ	64.0°
Z	51.00 m	κ	0.0°
DLT – straight lines (for initialisation)			
X	903.49 m	ω	9.83°
Y	71.23 m	φ	64.61°
Z	51.11 m	κ	-0.03°

spatial resection			
	points	straight lines	differences
X	905.039 m	905.002 m	$ \Delta X $ 0.037 m
Y	72.012 m	72.032 m	$ \Delta Y $ 0.02 m
Z	51.0871 m	51.0796 m	$ \Delta Z $ 0.008 m
ω	9.908°	9.919°	$ \Delta\omega $ 0.011°
φ	63.978°	64.020°	$ \Delta\varphi $ 0.042°
κ	-0.018°	-0.009°	$ \Delta\kappa $ 0.009°

Table 2. Results of the synthetic dataset

Comparing the results in Table 1 (real dataset) we can see that the “straight lines” method compared the point based method provides nearly the same result. Position differences are in the order of ~ 20 cm and differences for the orientation angles are in the order of 1-2 degree. As the point based estimation represents the optimal result, we can conclude that the errors occur by inaccuracies in the extraction of straight lines affected by the image quality and image resolution, or by inaccuracies in the distortion parameters. Considering the synthetic dataset in Table 2 which uses the same image coordinates for the point based method as well as for the straight line based method, we can see nearly the same result for the exterior orientation. This shows that the straight line based method is suitable to determine reliable results for the exterior orientation parameters.

4. CONCLUSION

In the article we have described the idea of the NEXUS platform, which offers the possibility to represent the real world as a world model. We have pointed out the key problem of LBS: “First the system has to determine where the mobile user is located at, than the system can provide support to the user.” Based on this key problem we have described general methods for location sensing and also a method, which uses scene analysis. For the method based on scene analysis we have presented an implementation of a process for estimating

improved position and orientation information. Also we have indicated problems of this method and we have presented some experimental results to show its successful operating.

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