FILTERALGORITHMS FOR OPTIMAL DETERMINATION OF POSITION AND ATTITUDE OF THE MOBILE MAPPING SYSTEM KISS

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KEY WORDS: FILTER, INS/GPS, KiSS.

ABSTRACT

The typical system for mobile mapping is built up as a multi sensor system, which includes sensor clusters for the determination of the trajectory and sensors for object measuring and positioning. One of these mobile mapping systems is the Kinematic Survey System (KiSS), which has been developed to capture all relevant data in a corridor of 50 m width on both sides of a route travelled with the survey vehicle. The vehicle is equipped with an inertial measuring unit in strap-down mechanization, a GPS-receiver, an odometer, a barometer, a video camera and a pair of CCD-cameras, all synchronized by the PPS-signal of the GPS-satellites. All sensor signals are recorded on a hard-disk while the vehicle is travelling with up to 70 km/h. The post mission data processing program provides the digitized trajectory and coordinates of all objects of interest in the field of view of the cameras.
To reach high accuracy, all data are pre-filtered and handled in a system of cascaded filters. A new approach will be shown to combine all data in a common Kalman Filter. It is based on a model of the movements of a body in three dimensional space. First projects verify the efficiency of the KiSS in establishing and updating databases of transportation routes.

KURZFASSUNG

Das typische mobile Erfassungssystem wird als Multisensorsystem aufgebaut, welches zum einen Sensoren zur Bestimmung der Trajektorie wie auch Sensoren zur Objekteinmessung beinhaltet. Das Subsystem zur Trajektorienbestimmung integriert weitere Subsysteme und Sensoren, wie GPS Empfänger, ein inertiales Navigationssystem (INS), einen Weggeber und/oder ein Barometer, um eine optimal geschätzte Position und Lage des Systems mit der angestrebten Genauigkeit zu erhalten.
Eines dieser Erfassungssysteme ist das kinematische Vermessungssystem (KiSS), das an der Universität der Bundeswehr entwickelt wurde, um alle relevanten Daten in einem 50 m breiten Korridor entlang der Straße mit Fahrtgeschwindigkeiten bis zu 70 km/h zu erfassen. Das Meßfahrzeug ist mit einem inertialen Navigationssystem , mit strapdown – Technologie, einem GPS-Empfänger, einem Weggeber, einem Barometer, einer Farbvideokamera und einem Paar CCD Kameras ausgerüstet, die alle mit dem PPS Signal der GPS-Satelliten synchronisiert werden. Alle Sensordaten werden während der Meßfahrt auf ein DAT geschrieben. In einem Nachverarbeitungsschritt werden die digitalisierte Trajektorie und die Koordinaten aller interessanten Objekte berechnet.
Um eine hohe Genauigkeit zu erreichen, werden alle Daten vorverarbeitet und in einem System kaskadierender Filter bearbeitet und schließlich in einem Kalman-Filter optimal kombiniert. Erste Projekte beweisen die Effizienz, mit der KiSS neue Datenbanken für Verkehrswege einrichten bzw. vorhandene aktualisieren kann.

1 INTRODUCTION

The economic development of a country depends to a high degree on the state of its network of lines of transportation. Therefore, highways, railroads and shipping routes have to be extended, improved and maintained permanently. Prerequisite to an efficient management of these public responsibilities is an up-to-date information system founded on a current database.

This information system contains the geometry and the topology of the transportation network, usually georeferenced, and attribute data, describing the condition, the capacity and the furnishings of the trade routes. It is usually designed as a special purpose geo-information-system (GIS).

The data acquisition for the databases is extremely costly since existing maps are usually outdated, incomplete and inaccurate, so that additional field survey is required to meet even moderate quality requirements and the data base must be updated with high frequency. A yearly revision rate of up to ten per cent has to be envisaged. The effort to keep up with these changes is often underestimated since the unavoidable field work is slow and expensive. An attempt to automate the field survey and thus to speed up and economize the data acquisition for building and updating databases is the development of the Kinematic Survey System (KiSS) at the Institute of Geodesy of the University of the Federal Armed Forces Munich.

2 REAL TIME DATA ACQUISITION WITH KiSS

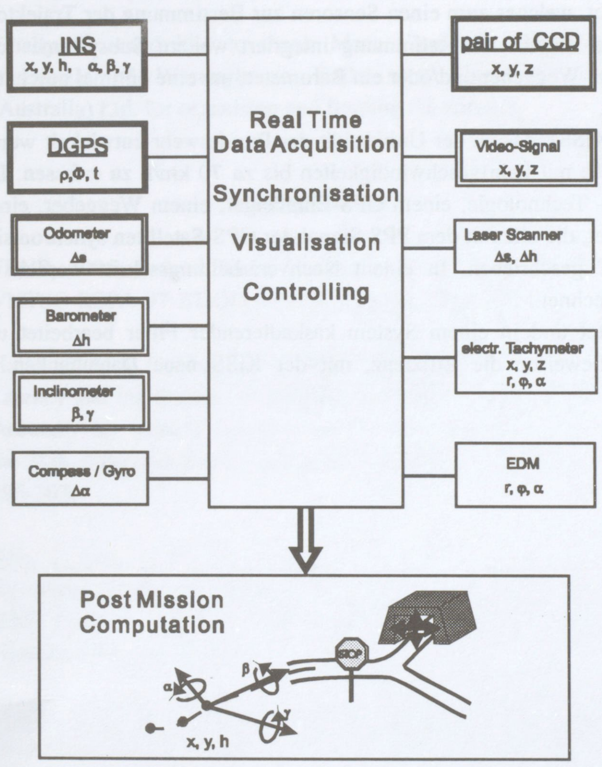

Figure 1: Overview of the Kinematic Survey System (KiSS)

The mobile measuring unit of the KiSS consists of two subsystems serving different purposes. The trajectory subsystem contains an inertial navigation system (INS) in strap-down mechanisation, featuring two two-axes mechanical, dry-tuned gyros and three accelerometers. This main sensor package provides autonomously position and attitude of the van at a high frequency.

Figure (1) shows an overview of all sensors of the KiSS. The sensors for the determination of the trajectory are placed in the left side of the scheme. Since the signals of inertial sensors are contaminated by progressive systematic deviations, aiding observations are required to obtain steady accuracy. These are zero velocities (ZUPT), when the van stands still, velocities from an odometer, heights from a barometer and DGPS-positions whenever four or more satellites are in view. The satellite fixes using pseudo-ranges have an accuracy of about 0.5 m and are provided with 5 Hz. The availability of DGPS is close to 80 percent, while the coverage of OTF-positions using phase measurements is below 20 per cent.

Figure 2: The mobile measuring system on the roof rack of the van

The second subsystem is composed of a pair of monochrome CCD-cameras which take simultaneously images of the situation in driving direction. Fig (2) shows the mobile measuring system with the GPS antenna and the CCD Cameras mounted on a roof rack of the van 1,80 m apart. They cover an area from 10 to 50 m in front of the van and 20 to 30 m to the right. So, driving both directions, all objects in a corridor of about 50 m are captured by the system. Additional information on objects along the route and on the condition of the roadway is provided by a color VHS video system and a voice recording unit. The sensor readings are synchronised with the PPS-signal of the Global Positioning System.

3 POSTPROCESSING CONCEPT

The evaluation of all sensor data is carried out after the data acquisition. The basic structure of this post-processing is outlined in figure (3). It consists of two independent parallel computations: the determination of the trajectory and the object recognition. Subsequent to this step is the setup of the data base, the determination of the alignment elements and the object positioning.

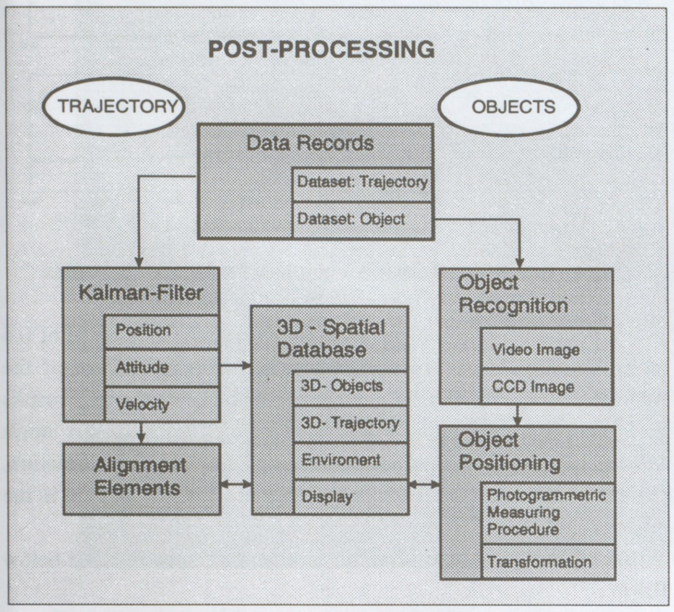

Figure 3: Overview of the post-processing concept

The determination of the trajectory is carried out by a cascaded filter system. The structure of this system is outlined in figure (4). It consists of two pre-processing steps and the main filter.

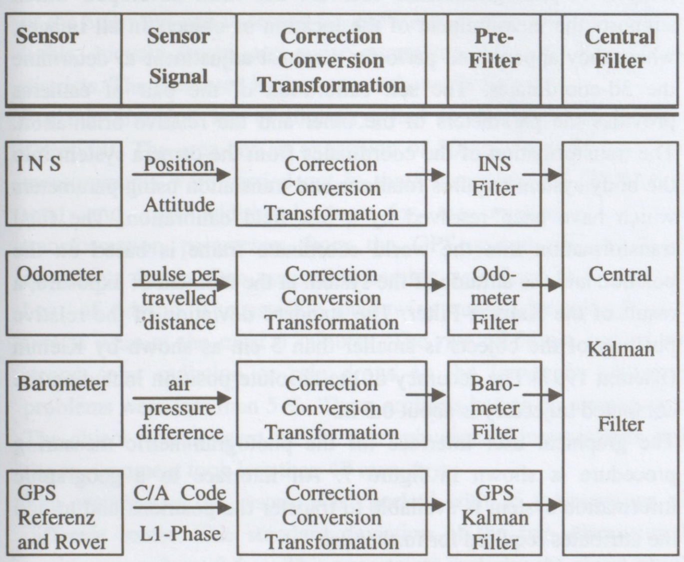

Figure 4: cascaded filter system with two pre-processing steps and central Kalman-Filter (including sensor signals)

3.1 Pre -filtering of the trajectory observations

In the first step of pre-processing the original measurement values are corrected and converted to pseudo-observations, like air pressure differences from the barometer readings to height differences.

In this step of the post-mission data processing it is also necessary to transform all the data from the individual sensor coordinate systems into a common reference frame. This is defined as the body system of the van with its origin given by the reference point of the IMU and axes parallel to the main axes of the van. This transformation is applied for both, position- and velocity determination.

The second pre-processing step consists of smoothing all pseudo-observations. The GPS Kalman filter is a completely independent Kalman filter, where the double-differenced pseudo-ranges from code measurement and the triple-differenced carrier phase measurements (phase rates) are processed as observations. Since changes in position can considerably be smoothed by GPS Kalman filtering all other pseudo-observations have to undergo filtering and smoothing algorithms in order to obtain the homogeneity of input data for central Kalman filtering. The filter-smoother automatically locates outliers and provides estimates of the precision. In order to obtain an optimal control on sensor signals and pseudo-observations, respectively, all sensors are pre-processed separately and subsequently combined in a central Kalman-Filter with feed-back.

3.2 Central Kalman Filter

The three-dimensional position as well as the velocity from GPS, the three rotation angles of the Inertial System, the velocity in direction of motion from the odometer and last not least the height change from barometer readings are introduced into the Kalman-Filter as observations. The observations are summarised in table 1.

observations	
x, y, h	3 D position from GPS
vx,vy,vh	3 D velocity from GPS
φx, φy, φz	Azimuth from INS
v odo	velocity from odometer
dh	height differences from barometer

Table 1: The observations of the main Kalman Filter

The theoretical and mathematical structure of the Kalman-Filter is an expansion of the one comprehensively described in (Wang 1997) and (Sternberg 1996, Sternberg 1998a) and therefore we have not to go into further details in this article. In contrast to conventional navigation filters being designed for the estimation of the error - state of the system, the position is directly estimated in this filter. Furthermore the azimuth, the tangential velocity of the system (equivalent to the velocity in moving direction) and the normal acceleration, which is perpendicular to the moving direction, are estimated in the main filter.

The mathematical model for the two-dimensional case was pointed out by Wang (Wang 1997). The expansion to three-dimensions and the fine tuning of the filter are completed. The elements of the state - vector and the process noise are shown in table (2) .

state – vector	
x, y, h	3 D position
α	Azimuth
vt	tangential velocity
an	normal acceleration
	calibration parameters

process noise	
at	tangential acceleration
jn	normal jerk

Table 2: The elements of the state vector and the elements of the process noise

All observations are processed in a forward and a backward filter. The estimated state-vectors from both filters are combined in an optimal smoothing algorithm. Besides the digitised trajectory in terms of coordinates, attitude angles and velocities at every PPS-second, which coincides with the moment of shooting of the CCD-cameras, the expanded filter provides estimates of calibration parameters for the sensors. The accuracy of the filtered points is about 0.5 m in a UTM coordinate system based on WGS 84. In the final step the sequence of points is replaced by a smooth line consisting of geometrical elements (straight sections, transitional and circular curves) forming the alignment of the road.

3.3 Filter results

To analyse the filter behaviour and the filter results control points were established on the former airport of Neubiberg, near Munich. This airport is suitable for the test, because it features optimal conditions for GPS measurements and optimal geometry for the vehicle path like long straight lines with no height differences. The airport and the path of a driven test route is shown in figure 5.

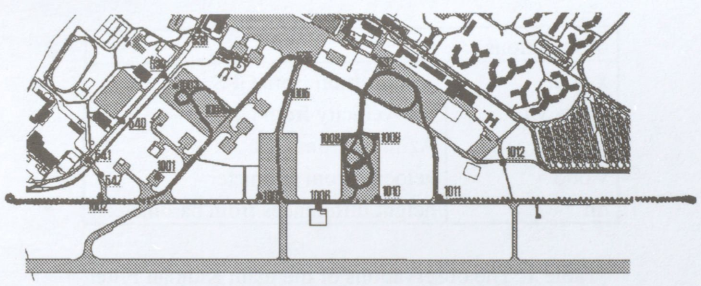

Figure 5: Airport Neubiberg with vehicle path

In this test at least 5 satellites were in view, enabling the computation of OTF solutions as a reference. A total outage of all satellites for 60 seconds was simulated to check the main filter. During the outage the vehicle is on the taxiway, which is oriented in west-east direction. In figure 6 the position differences between the OTF positions and the results of the forward filter, of the backward filter and of the smoothing algorithm respectively are shown.

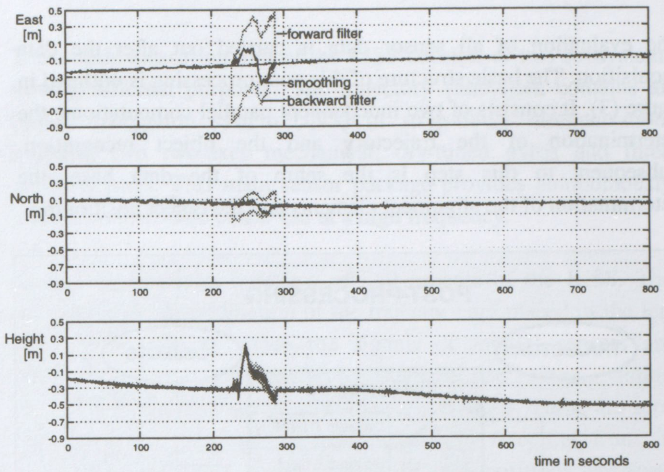

Figure 6: Results of the filter compared with OTF positions

From the direction of movement at the outage the difference of 0.6 m in the east component can be attached to a scalefactor of the odometer. The length of the outage is about 1200 m, which results in a scalefactor of about 0.05 %. The difference in the north direction, which is perpendicular to the moving direction, correspond to a gyro drift of about 0.08 ° / h. Both values are in the error budget of the sensors.

With the smoothing algorithm the divergence can be reduced below 0.4 m.

3.4 Object measurement

By screening the video, the objects of interest are identified and flagged for measurement. Since the video is synchronised with the CCD-cameras, it is easy to find the flagged objects in the digital images. A photogrammetric software has been developed which supports the measurement of the location of objects in all images, where they appear, and performs a robust adjustment to determine the 3d-coordinates. The self calibration of the pair of cameras provides the parameters of the inner and the relative orientation. The transformation of the coordinates from the camera system into the body system requires rotations and translation using parameters which have been resolved by a test field calibration. The final transformation into the world coordinate frame is based on the position and the attitude of the system at the moment of exposure, a result of the Kalman-Filter. The standard deviation of the relative position of the objects is smaller than 5 cm as shown by Klemm (Klemm 1997).The accuracy of the absolute position including the computed trajectory is about 0.5 m.

The graphical user interface for the photogrammetric measuring procedure is shown in figure 7. An interface to a geographic information system is available to transfer the positions and to add the attributes required for further use.

Figure 7: Object Measurement with KiSS and attributes for geographic information systems

4 EFFICIENCY AND ACCURACY Of KiSS

In a pilot project, the efficiency of the system could be demonstarted. The aim of the project was to determine the traverse of the highways and to record the environment, the junctions, traffic lights, bicycle tracks and noise protection walls in three rural districts. The measured highways are shown in figure 8.

For this aim 660 km of highways had to be measured in both directions. The area has an expansion of 50 km times 80 km. The measurements were carried out in three campaigns of 16 days in total and two additional days for the evaluation of the transformation parameters from the GPS system to the local coordinate frame. One measuring session was fixed to about one hour of driving. The satellite shadowing caused by villages and forests were at the most 5 minutes. The rate of failure caused by strong solar radiation or rain drops on the lenses or hardware problems were less than 5 %. These sections had to be remeasured. The object measurement for the determination of intersections and the environment took less than 40 man-days.

The accuracy of the system was checked with 25 intersections of different routes. The standard deviation of the two dimensional position was about 0.6 m. This uncertainty includes the errors of all sensor calibrations, including the photogrammetric calibration of the CCD sensors, the errors in the determination of the trajectory as well as the errors of the object measuring.

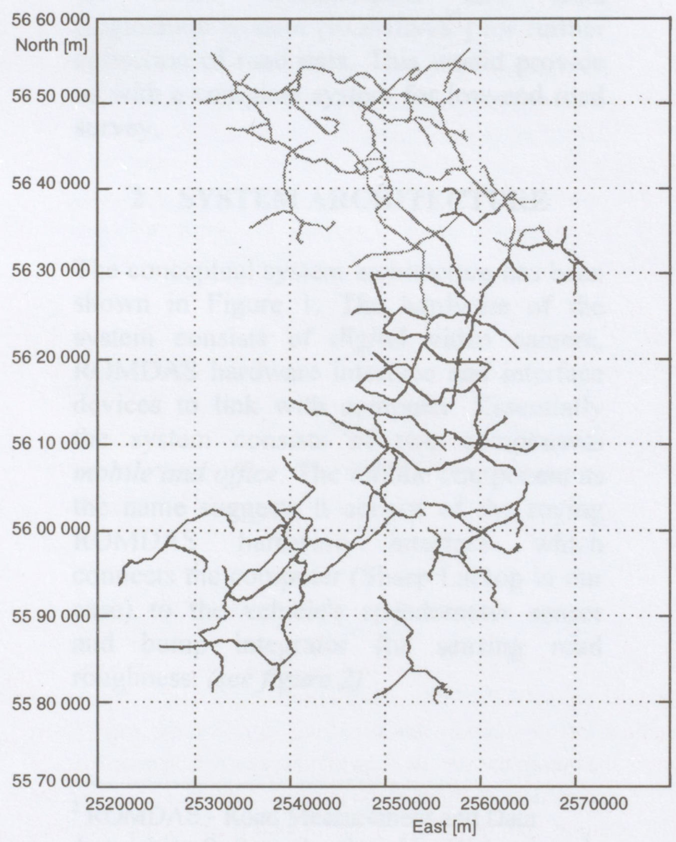

Figure 8: Streets and intersections

5 OUTLOOK

The efficiency and the accuracy of the Kinematic Survey System KiSS have been verified in the pilot project. Next step will be an improvement in both aspects.

To increase the efficiency the work flow of the post-mission data processing is under further development with the aim to automate all possible steps. In order to enhance the accuracy of the system, additional sensors, like laser scanners, and more accurate inertial navigation systems will be tested and installed.

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