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USING EARTH OBSERVATION PAYLOAD RESOURCES FOR AUTONOMOUS ON-BOARD NAVIGATION OF LEO-SATELLITES

K. Janschek[1], T. Boge[1], M. Buchroithner[2], K.-P. Döge[1]
Technische Universität Dresden,
[1] Institute of Automation, [2] Institute of Cartography
D-01062 Dresden, Germany

ABSTRACT
The applicability of using onboard earth observation payload resources for landmark navigation is investigated. The reference mission “Satellite based Monitoring of Mobile Object” uses an earth observation camera for road traffic monitoring purposes and allows perfectly the maximum use of payload resources in the sense, that both the camera as sensor device and a large part of the follow-on image processing functions can be used “free of charge” for the generation of navigational landmark data.
The paper discusses the overall system architecture, different filtering options based on Extended Kalman Filters and gives performance results verified by simulation for backup (magnetometer/landmark) operation. Furthermore a thematic onboard data reduction algorithm is presented, which allows an automatic extraction of road data to generate landmarks.
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1. INTRODUCTION

The prospective commercial importance of LEO satellite constellations for extended services beside pure telecommunication e.g. road traffic telematics using earth observation (EO) services, puts the emphasis on the availability of appropriate cost optimized system solutions. One of the most mission critical onboard functions of any satellite , in particular for EO-applications, is apparently the navigation function, which is in charge of determination of the instantaneous satellite orbital position and attitude.
Visibility constraints and cost optimized ground operations support requirements call for a considerable high operational autonomy for this function [3].
The objective of the approach presented in this paper is to reduce the overall cost for the realisation of the navigation function by a reduction of the total number of equipment (minimum hardware approach) and substitution of hardware functions and hardware redundancy by advanced data processing techniques (information fusion) [5].
The paper presents first results of backup navigation (magnetometer/landmark-navigation) which have been derived for the TUD-Satellite demonstration mission “Satellite based Monitoring of Mobile Object” as application reference [4]. This mission uses a micro-satellite in LEO-orbit (500km, 53° inclination) with an high resolution earth observation camera for road traffic monitoring purposes.

2. NAVIGATION CONCEPT - REFERENCE HARDWARE BASELINE

The onboard equipment of the minimum hardware navigation system comprises the following devices (see Figure 1):

- <u>One</u> integrated GPS/GLONASS receiver for the determination of position and attitude.
- <u>One</u> 3-axes magnetometer for coarse estimation of position and attitude at any moment.
- <u>One</u> Earth Observation (EO) camera used as a payload device (including the payload specific image processing software) and available for more accurate estimation (in comparison with magnetometer) of position and attitude.
- <u>Two</u> redundant onboard computers
- <u>Two</u> redundant serial data busses

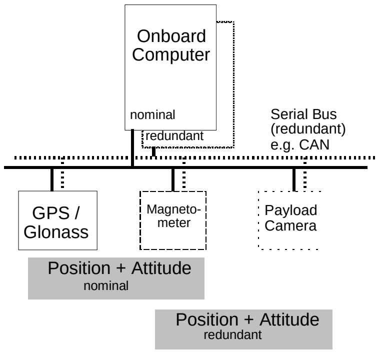

Fig. 1 Reference architecture

Besides the EO-camera all devices of this reference architecture belong to the standard equipment of a typical LEO telecommunication and earth-observation mission.

3. BACKUP NAVIGATION

The backup navigation is based on magnetometer and landmark navigation [1]. Preliminary investigations on the capabilities of fusion of the two information sources have been performed. The investigated fusion algorithm is based on a centralized Extended Kalman Filter (see Figure 2), which uses directly the continuously available magnetometer data and asynchronous land-mark data. This configuration is preferred against the fusion of the outputs of the individual magnetometer and landmark navigation filters (i.e. decentralized), because in the current case any of the filters would be implemented in the onboard computer anyway. This allows to use the different measurements directly for the updating of a filter using common states.

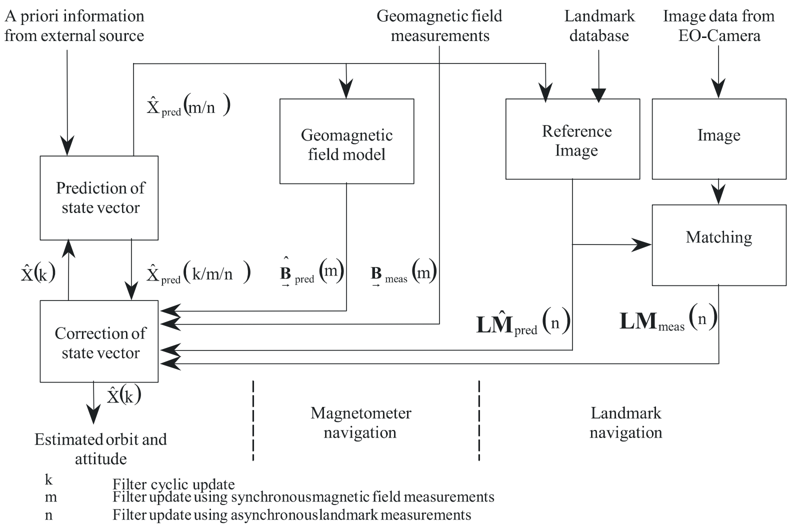

Fig. 2: Principle structure of backup navigation

4. LANDMARK RECOGNITION AND PROCESSING

If the payload earth observation tasks incorporate already some thematic preprocessing of the images then the extra effort for navigational image processing can be reduced considerably. This is just the case for the TUD-Satellite reference mission.

For the purpose of *road traffic monitoring* the most important information is contained in the roads itself. It is therefore sufficient to downlink only those parts of the images,

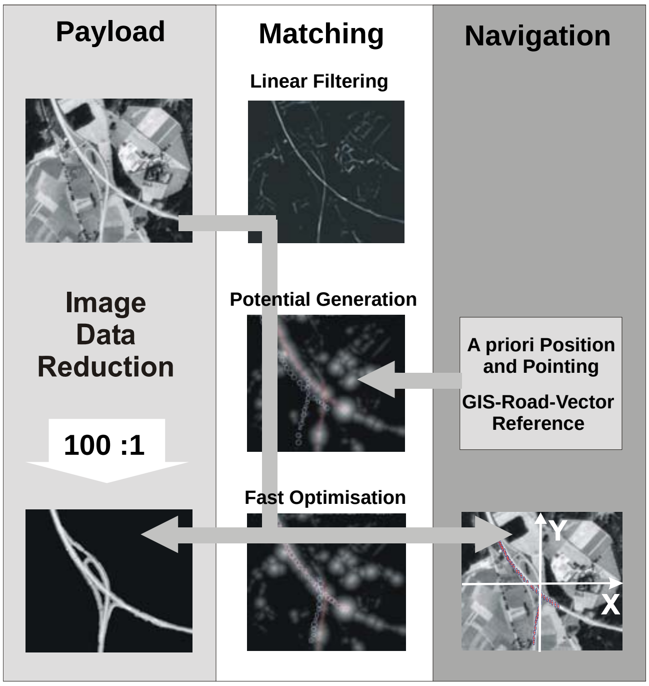

Fig. 3: Image data reduction algorithm

which contain road data. This reduces tremendously the required downlink budgets up to a factor of 100.

A *thematic data reduction algorithm* has been developed for this purpose, which allows to mask out the road information from the image [6] (see Figure 3).

The method requires a consistent data set of the road middle axis (vector reference) augmented by a local estimation of the road width and a global estimation of the mean gray value of the road surface. They are stored as GIS-vector (GIS-Geographic Information System) reference data in the on-board computer. Starting with a rough estimation of the actual position and pointing of the satellite, an a-priori pixel structure of the roads in the image is calculated. The iterative matching process (“Fast Optimisation”) recognizes typical road image patterns and compares them to the a-priori pixel structure using a potential field (“Potential Generation”) derived from a target-specific filtered image (“Linear Filtering”). After the successful matching all other image information is masked out.

It is now obvious to use this road data directly as landmarks, because all prerequisites for landmark generation are fulfilled perfectly. The landmark navigation requires information on the position of the landmark (= road) on the ground and the position of the landmark in the current image. The position on ground is stored in the GIS-vector on-board reference and the position in the image is calculated from the actual matching process.

Important for the navigation filter develop-ment is the performance and error characteristic of the proposed landmark recognition and processing algorithm. Figure 4 shows the result of the investigation of maximum a priori position error using different width of the generated potential field [2].

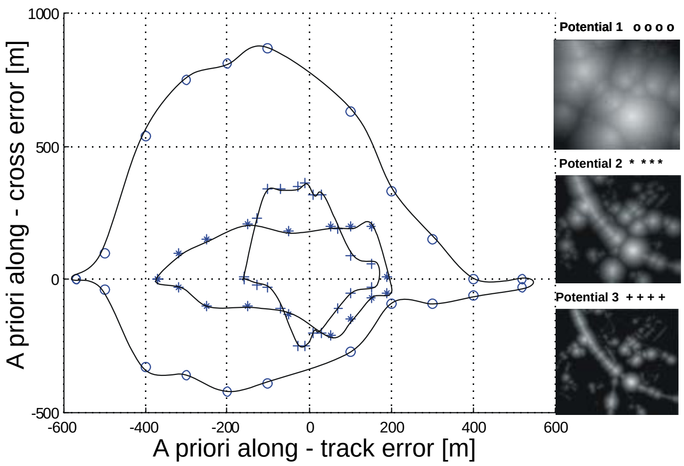

Fig 4: Maximum a priori position error using different width of potential field

5. BACKUP POSITION ESTIMATION USING MAGNETOMETER AND LANDMARKS

The study of accessible estimation performances based on the sole use of one backup sensor alone (magnetometer, landmark) shows clearly the limitations of single information sources. Magnetometer based information suffers from measurement errors resulting mainly from geomagnetic field uncertainties [7] (position accuracy about 8-10km). Landmark based information suffers from rare updates due to road availability and disturbing weather conditions (clouds), which results in long filter propagation periods [5] (position accuracy about 4-6km).

The simulation results for the centralized magnetometer/landmark filter show clearly the benefits of information fusion, because the estimation accuracy improves considerably. A typical simulation result is shown in Figure 5, assuming only *two* landmark updates per orbital period

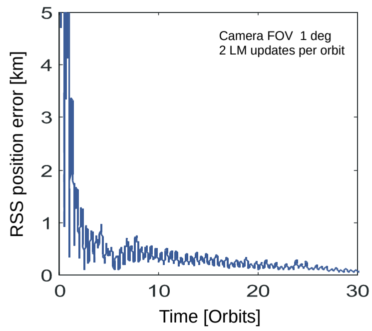

Fig 5 Positions estimation error of Magnetometer and Landmark navigation

6. SUMMARY

This paper describes a minimum hardware navigation concept for LEO satellites based on the maximum-use principle of any onboard equipment. The combination of navigational equipment (magnetometer), payload equipment (earth observation camera) and subsequent information fusion algorithms supports the application of the functional redundancy concept to meet redundancy requirements as well as performance requirements. First results are presented, which have been derived for the TUD-Satellite mission dealing with road traffic monitoring. The results for backup position estimation show the capabilities of information fusion and allow some first estimation on reachable performances. A thematic data reduction algorithm is presented, which supports in an efficient way the resource critical task of onboard landmark recognition and processing.

7. REFERENCES

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