AUTOMATED DETECTION AND CLASSIFICATION OF INTACT ROAD NETWORKS IN MULTI-SENSORIAL SPACEBORNE IMAGERY FOR NEAR-REALTIME DISASTER MANAGEMENT

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In this paper, we describe and evaluate an image analysis system for the automated verification of intact roads from multi-sensorial spaceborne imagery. This system is designed to support rescue teams during the reaction on natural disasters such as floodings, landslides or earthquakes. Hence, verification of intact roads comprises both the identification of roads as well as the classification of accessible/intact and inaccessible/damaged roads. Depending on the type and complexity of the input data, the system can be run in a fully automatic or semi-automatic mode, where a human operator can edit intermediate results to ensure the required quality of the final results.

The system is divided into two main parts. The first part deals with the detection and (internal) evaluation of roads in high resolution satellite images, while the second part classifies the detected roads into accessible and inaccessible road segments. The second part also delivers internally computed quality values to assess the reliability of the results.

The novelty of the presented work refers mainly to two points: Firstly, the system is able to assess the drivability of roads and thus extends common road extraction approaches; secondly, the different image processing modules are embedded into a comprehensive systemic approach enabling the utilization of different types of input data depending on their availability (multi-spectral and/or SAR imagery, digital elevation models and external Geo-Information data).

Road Detection:

The initial extraction of roads is done automatically with an improved version of the system of (Wiedemann & Hinz, 1999; Wiedemann & Ebner, 2000; Wiedemann, 2002). The first step consists of a line extraction in each image, followed by attribute extraction. Based on these attributes the uncertainty of each line segment is estimated, followed by an iterative fusion of lines detected in separate channels or images. The fusion takes the uncertainties as well as context information and sensor geometry into account. On the basis of a resulting uncertainty vector each line obtains an estimation of the probability that the line really belongs to a road. The final step includes the generation of a road network by calculating optimal paths through the weighted graph of line segments and connections between them. By this, also missing or occluded road sections can be bridged. The results of this phase are internally evaluated using the self-diagnosis scheme described in (Hinz & Wiedemann, 2004). The aim is to derive a priority list of road segments, which should be checked in a subsequent process. Roads which could be detected with high reliability are labeled “green”, detections likely being false alarms are labeled “red” and uncertain decisions of the system are labeled “yellow”.

Depending on the number of uncertain road segments, the operator may call semi-automatic road extraction modules to edit and complete the result. The user can chose three types of interactive tools to connect road parts: The first possibility is to use a snake-based approach incorporating topological knowledge of networks as introduced in (Butenuth, 2007; Butenuth, 2008). This method is especially efficient if larger parts of the network need to be edited or refined, as only a few clicks are necessary to initialize topology and coarse layout of the missing (sub-)network. The second opportunity is an algorithm for road tracking as outlined in (Baumgartner et al., 2002). It supports the efficient bridging of small gaps in the extraction result. The third possibility is the manual digitizing of missing road parts by the user, which is in particular mandatory if larger parts of a road are completely occluded.

Road Classification:

The second part of the road verification system consists of classifying road segments into accessible/intact and inaccessible/damaged roads. Please note that, instead of the road network derived from the images, also existing road data exported from Geo-Databases could be included at this point. It must be assured, however, that the database information is consistent with the images in terms of geometric precision and up-to-dateness.

A supervised Bayesian classification using radiometric features along the detected road segments and optionally a height model is embedded into a fuzzy reasoning scheme. The Bayesian classification assigns probability values to the input segments being the class “intact road” or potential other objects such as “flooded road”, “damaged road”, “forest”, or “cloud”. The probability values are combined by fuzzy reasoning whose result are membership values for each road segment belonging to the class “intact road”, “inaccessible road” or “uncertain decision”. Currently, we use hand-crafted fuzzy functions for weighting and combining the probabilities. Future studies will focus on the automatic learning of these functions from sample data to allow for a whole reasoning process formulated as Bayesian network.

A graphical user interface provides details about the reasoning process for each road segment to the user, in order to efficiently check the result. Under the assumption that the classification of intact and inaccessible roads is correct, the user has to check only the “uncertain decision” class. In order to assess the validity of this assumption, the final results have been compared with hand-crafted reference data.

Performance evaluation:

The focus of the performance evaluation is put on road classification and not on road detection, since a possibly incomplete result of road detection can be edited by the above-mentioned interactive tools. Thus, we can assume the road detection to be reasonably correct. To acquire reference data, we used an existing road database and checked its consistency with the imagery. A human operator classified the road segments into “intact”, “inaccessible” and “uncertain”. The latter class is necessary to include into the reference data, as in some cases also an experienced cartographer is not able to decide whether a road can be passed or not. Such situations appear, for instance, when a road is only slightly flooded or partly occluded by trees.

With the current implementation of the system, 78% of the road segments of an 11km by 11km Ikonos scene is classified correctly (i.e. “intact” or “inaccessible”). The false alarm rate of road classification is considerably low, as only 5% of the road sections are assigned to the wrong class (i.e. classified “intact” but in reality “inaccessible” and vice versa). Finally, 17% of the road sections are assigned to the “uncertain” class. In summary, only 1/6 of the classified road network needs to be checked manually in order to reach a correctness of 95%.

These values were reached for multi-spectral data including height information. Future validations of the system performance will include the quality of the results depending on the availability of height models and also include SAR data.

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