Remote sensing minefield area reduction: Model-based approaches for the extraction of minefield indicators

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In the last decade, several humanitarian demining actions have acknowledged the role of remote sensing as a useful tool, able to enhance the productivity, cost-effectiveness and safety of ground-based minefield detection methods [1] [2] [3] [4]. Air- and space-borne platforms, equipped with multiple sensors, can quickly and safely scan large inaccessible areas. Remote sensing can contribute to the mapping and identification of suspected areas, and eventually to the determination of the minefield boundaries, through the extraction of suitable direct and indirect minefield indicators. The identification of image indicators, in combination with collected ancillary information, prior knowledge/intelligence, can assist in conventional General Mine Action Assessment and Technical Surveys prior to a clearance (demining) campaign and implicitly highlight areas of high risk.

Minefield indicators are conventionally identified via visual image interpretation, by experts with in-depth field knowledge and experience. This process is carried out either through spontaneous recognition, through recollection of object features (such as color, texture, size, shape, shadow), or using a process of logical inference. Despite its effectiveness, visual interpretation however can become intractable in cases of huge volumes of data, where automatic image analysis techniques could be more effective. However systems for automatic image analysis should detect visually perceivable image entities that carry semantic interpretation for an expert observer.

In this paper, we demonstrate the potential of computer vision techniques, which meet this requirement, for the automated extraction of minefield indicators in rural areas with heavily cluttered environments. We have developed a series of model-based methods for the detection of regions/objects/structures with a versatile appearance in terms of size, shape and spectral/textural signatures. The investigated techniques, classified according to each considered type of minefield indicator, are listed.

Linear structures: Minefield indicators of this type include elongated structures related to warfare activities (e.g. trenches), roads and paths that designate safe passage areas, protection walls, rivers and geological erosions. We have developed a model-based approach for the identification of linear structures, which follows assumptions concerning their geometric and radiometric properties [5]. During a local analysis step, the detection of elongated structures is performed by applying a series of morphological filters. The main axis of the extracted elongated structures is determined by applying the watershed transformation on the response of the morphological filtering. The response values along the watershed lines, together with information about orientation, is then used as an input to a line-following algorithm that produces a set of line segments. During a global analysis step, the produced line segments, together with an additional set of segments that correspond to all possible connections between them, are organized as a graph. The nodes of the graph are associated with an observation field and a dedicated Markov Random field (MRF) that describes the geometrical properties of the linear structures of interest. Using a binary set of interpretation labels, the final result of optimal connected configurations (optimal graph labeling) is then extracted based on a maximum a posteriori probability (MAP) criterion. The main advantage of our approach is its high detection performance in heavily textured environments and its ability to identify elongated structures of different size.

Buildings: The presence of buildings, which correspond either to residences or parts of an industrial infrastructure, can be considered as a major indicator of low risk areas with human activity, or potential targets during warfare. We have investigated the possibility of identifying building rooftops from a single remotely sensed image, without the use of digital terrain models or stereo vision. Our approach is based on an image interpretation model, which combines both 2-D and 3-D contextual information of the imaged scene [6]. A hierarchical graph of rooftop hypotheses is constructed using a contour-based grouping hierarchy (by employing the principles of perceptual organization) and additional 3-D evidence, originated from the presence of shadows and vertical walls. We associate an observation field of saliency measures to the resulted hypothesis graph, while the significance values of its nodes are considered as the realization of a hierarchical, Markovian field of labels. Finally, a hypothesis verification step (optimal graph labeling) is carried out via a stochastic labeling scheme, based on a MAP criterion.

Fencing systems: Several fencing systems are frequently used in order to designate the locations of high risk in mine infected areas. We have developed an automated approach for the identification of fencing indicators that exhibit a regular pattern in terms of co-linearity and periodicity. A representative example is the case of periodically placed poles, with their shadow oriented in a certain direction. The method initially involves an oriented denoising algorithm, followed by a shadow detection method, based on the HLS color space representation of the image. The Hough transform is used for the detection of the principal orientations (co-linearity criterion), while linear patterns that exhibit equal spacing regularity are then selected using the FFT transform (periodicity criterion) [3].

Land cover: One of the requirements of an air- or space-borne minefield area reduction system is the characterization of the land cover of the surveyed area. Its major aim is the discrimination between areas of human activity (e.g. residential areas, agricultural fields) and natural undisturbed environments (areas with high and dense vegetation). In the case of high resolution airborne images, the defined land cover classes have a non homogeneous appearance with respect to spectral and textural responses, something that hampers the classification efficiency of conventional pixel-based classifiers (like Maximum Likelihood, fuzzy c-means clustering, neural networks). Taking into account this constraint, we have investigated a variety of classification approaches based on the framework of Markov Random Field theory, in order to capture contextual information, in terms of spatial consistency. The investigated methods involve non-causal energy-based models defined on the image lattice, hierarchical, multiresolution models defined on pyramidal representation of the image, as well as hierarchical Markovian models defined on the hierarchy of multiscale region adjacency graphs [7].

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