Knowledge-Assisted Image Analysis Based on Context and Spatial Optimization

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ABSTRACT

In this article, an approach to semantic image analysis is presented. Under the proposed approach, ontologies are used to capture general, spatial, and contextual knowledge of a domain, and a genetic algorithm is applied to realize the final annotation. The employed domain knowledge considers high-level information in terms of the concepts of interest of the examined domain, contextual information in the form of fuzzy ontological relations, as well as low-level information in terms of prototypical low-level visual descriptors. To account for the inherent ambiguity in visual information, uncertainty has been introduced in the spatial relations definition. First, an initial hypothesis set of graded annotations is produced for each image region, and then context is exploited to update appropriately the estimated degrees of confidence. Finally, a genetic algorithm is applied to decide the most plausible annotation by utilizing the visual and the spatial concepts definitions included in the domain ontology. Experiments with a collection of photographs belonging to two different domains demonstrate the performance of the proposed approach.

Keywords: context; knowledge-assisted analysis; multimedia ontologies; semantic annotation; semantic image analysis

INTRODUCTION

Recent advances in both hardware and software technologies have resulted in an enormous increase of the number of images that are available in multimedia databases or over the Internet. As a consequence, the need for techniques and tools supporting their effective and efficient manipulation has emerged. To this end, several approaches have been proposed in the literature regarding the tasks of indexing, searching, and retrieval of images.

The very first attempts to address these issues concentrated on visual similarity assessment via the definition of appropriate
quantitative image descriptions, which could be automatically extracted and suitable metrics in the resulting feature space. Coming one step closer to treating images the way humans do, these were later adapted to a finer granularity level, making use of the output of segmentation techniques applied to the image (Smeulders, Worring, Santini, Gupta, & Jain, 2000). While low-level descriptors, metrics, and segmentation tools are fundamental building blocks of any image manipulation technique, they evidently fail to fully capture the semantics of the visual medium by themselves; achieving the latter is a prerequisite for reaching the desired level of efficiency in image manipulation. To this end, research efforts have concentrated on the semantic analysis of images, combining the aforementioned techniques with *a priori* domain specific knowledge, so as to result in a high-level representation of images (Al-Khatib, Day, Ghafoor, & Berra, 1999). Domain specific knowledge is utilized for guiding low-level feature extraction, higher-level descriptor derivation, and symbolic inference.

Depending on the adopted knowledge acquisition and representation process, two types of approaches can be identified in the relevant literature: implicit, realized by machine learning methods, and explicit, realized by model-based approaches. The usage of machine learning techniques has proven to be a robust methodology for discovering complex relationships and interdependencies between numerical image data and the perceptually higher-level concepts. Moreover, these elegantly handle problems of high dimensionality. Among the most commonly adopted machine learning techniques are Neural Networks (NNs), Hidden Markov Models (HMMs), Bayesian Networks (BNs), Support Vector Machines (SVMs), and Genetic Algorithms (GAs) (Assfalg, Berlini, Del Bimbo, Nunziat, & Pala, 2005; Zhang, Lin, & Zhang, 2001). On the other hand, model-based image analysis approaches make use of prior knowledge in the form of explicitly defined facts, models, and rules (i.e., they provide a coherent semantic domain model to support “visual” inference in the specified context) (Dasiopoulou, Mezaris, Kompatsiaris, Papastathis, & Strintzis, 2005; Hollink, Little, & Hunter, 2005).

Regardless of the adopted approach to knowledge representation, the inclusion of spatial information in the knowledge exploited during the analysis process makes necessary the definition and extraction of spatial relations from the visual medium. The relevant literature considers two categories of approaches for the latter task: angle-based and projection-based approaches. Angle-based approaches include Wang, Makedon, Ford, Shen, and Golding (2004), where a pair of fuzzy k-NN classifiers are trained to differentiate between the *Above-Below* and *Left-Right* relations, and the work of Millet, Bloch, Hede, and Moellic (2005) where an individual fuzzy membership function is defined for every relation and applied directly to the estimated angle-histogram. Projection-based approaches include Hollink et al. (2004), where qualitative directional relations in terms of the centre and the sides of the corresponding objects’ MBRs were defined, and Skiadopoulos et al. (2005), where the use of a representative polygon was introduced.

Furthermore, in the real world, objects exist in a context. Representing context is a research issue of great importance (Edmonds, 1999) affecting the quality of the produced results, especially in the field of multimedia analysis in general and knowledge-assisted image analysis in particular. The latter can be defined as a tightly coupled and constant interaction between low-level image analysis algorithms and higher-level knowledge representation (Athanasiadis et al., 2005), an area where the role of context is crucial. In recent years, a number of different context aspects related to image analysis have been studied, and a number of different approaches to model context representation have been proposed (Zhao, Shimazu, Ohta, Hayasaka, & Matsu-shita, 1996).

In this article, an approach to knowledge-assisted image analysis based on coupling explicit prior knowledge in the form of prototypical instances, spatial relations, and
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