Information Sciences 366 (2016) 177–187

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Vehicle detection from highway satellite images via transfer learning

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ARTICLE INFO

Article history:
Received 15 June 2014
Revised 1 October 2015
Accepted 2 January 2016
Available online 20 February 2016

Keywords:
Classification
Satellite images
Transfer learning
Sparse coding

ABSTRACT

Coming with the era of highway satellites, nowadays there is a massive amount of remote sensing images captured. Therefore, it is now feasible to detect vehicles directly from these satellite images, which has attracted extensive research attentions for both academic and industrial applications. However, it is not an easy task at all, mainly due to the difficulty to obtain training data to train vehicle detectors. On the contrary, there has been sufficient amount of labeled information regarding vehicle regions in the domain of aerial images. In this paper, we study the problem of detecting vehicles on highway satellite images, without the time-consuming step of collecting sufficient training data in this domain. Our key idea is to adopt a novel transfer learning technology that transfers vehicle detectors trained in the aerial image domain to the satellite image domain. In doing so, several cutting-edge vehicle detection algorithms can be directly applied. More specifically, our transfer learning scheme is based on a supervised super-resolution algorithm, which learns mutually correlative sparse coefficients between high and low resolution image patches. Then, a linear SVM based detector is trained, the loss function of which is integrated into the sparse coding operation above. Experimental results have shown that the proposed framework can achieve significant improvement over several alternative and state-of-the-art schemes, with high precision and low false alarms.

1. Introduction

Coming with the era of highway satellites and high-resolution imaging techniques, nowadays traffic data can be quickly acquired by using satellite images. Comparing to the traditional method of traffic monitoring that relies on surveillance images or aerial images, traffic monitoring using satellite images merit in its high convenience, low cost, as well as good safety. And the resolution of satellite imagery has been significantly improved, for instance many high-resolution satellites provide 0.5–1 m resolution panchromatic images, such as IKONOS (1m), QuickBird(0.61 m), WordView(0.5 m), etc. Although it is still not comparable to aerial images or surveillance images, the resolution of satellite images is already sufficient for traffic monitoring. Therefore, traffic monitoring using highway commercial satellite images has become a research hot spot in recent years. Among various tasks of traffic monitoring, vehicle detection is one of the core challenges, which has several real-world applications such as battlefield directing and intelligent transportation, etc.

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http://dx.doi.org/10.1016/j.ins.2016.01.004
0020-0255/

In the literature, vehicle detection from aerial images has attracted extensive research focus in the past years. Different from that of highway satellite images, aerial images are typically with a spatial resolution of 0.35 m or less [4,11,20,25,26], which contains more details on vehicle appearances and backgrounds. In this resolution level, a wealth of robust cutting-edge detectors can be directly used for vehicle detection with high accuracy, meanwhile there are rich training instances and datasets available in the literature. For example, the works in [1,3] focus on detecting moving cars by using airborne optical sensors. The work in [12] focuses on detecting stilling or parking vehicles by supervised sliding window search. In general, the existing approaches for vehicle detection in aerial images can be categorized according to the features used in the methods, i.e.:

- Explicit model [10,12,19], which clusters similar pixels into potential vehicles. Such method usually describes a vehicle as a box, and adopts a top-down matching scheme to find the best-matched candidate in the satellite image. For instance, Hinz [10] proposed a 3D car model based on significant edges. Holt et al. [12] and Lenhard et al. [19] adopt object detection schemes to train car detector.
- Implicit model [15,16], which extracts intensity or texture features surrounding each pixel to implicitly model the vehicle, for instance surrounding contour [16] or histograms of oriented gradients [15]. In the implicit model, a vehicle is usually described by using wire-frame representation. And the detection is performed by checking features surrounding the target region.

To train a robust vehicle detector with high accuracy, the existing works typically needs high-resolution aerial images together with sufficient amount of training samples. The former ensures sufficient details in modeling the appearance of vehicles, while the latter ensures sufficient samples in detector training. However, this is a big challenge when facing low-resolution images captured from highway satellites. One limitation is the resolution, i.e., panchromatic band resolutions of images captured from highway satellites are presently in the range of 0.41–1.0 m. Another limitation is the number of training instance in that resolution. To the best of our knowledge, Correspondingly, limited work has been proposed in the literature to study vehicle detection in low-resolution satellite images [8,14,24,28]. And the above works mainly focus on detecting sparse vehicles on roads.

For a brief review, recently an automatic vehicle detection method was proposed in [6], which can be based for panchromatic images, multi-spectral image of QuickBird satellite, as well as road network data. Leitloff et al. [18] presented an automatic vehicle detection method for satellite images, which adopts an adaptive detector learning scheme by using Haar-like features. He et al. [9] presented a supervised classification and thresholding method to extract traffic information in high resolution satellite images. Mantrawadi et al. [21] proposed an object identification algorithm for high-resolution satellite images based on data mining and knowledge extraction. More recently, Chen et al. [2] proposed a deep learning based vehicle detector.

In this paper, we propose a robust vehicle detection algorithm for low-resolution highway satellite images, which handles the challenges of both low-resolution and few training samples. Our key innovation is to transfer this problem to the high-resolution aerial image domain, where robust and cutting-edge detectors can be learned. To this end, we proposed a supervised transfer learning scheme which consists of three steps as follows:

- A super resolution framework to transfer the detection task in low-resolution satellite image domain to high-resolution aerial image domain.
- A sparse-coding based reconstruction algorithm that integrates classifier training into the super resolution process, which makes the transferred patches in high-resolution more discriminative to train vehicle detectors.
- A robust vehicle detection via linear SVM based search that supports large-scale parallel.

The output of our framework is a robust vehicle detector run on the low-resolution satellite image domain. Such detector has achieved sufficient accurate that has the potential to be directly used for real-world applications of traffic analysis and road surveillance in military and transportation systems.

The rest of this paper is organized as follows: In Section 2, we introduce the proposed super resolution based transfer learning framework. Then, Section 3demonstrates and analyzes the experimental results. Finally we conclude this paper in Section 4 and discuss our future work.

2. The super-resolution detector transfer framework

2.1. The proposed framework

We first briefly review the overall flowchart of the proposed framework for super-resolution detector transfer.

In preliminary, we assume that vector maps are available to assist the extraction of road area. Nevertheless, other complex algorithms for road detection and segmentation can be deployed without the above assumption. And the step of road detection is not the core contribution of this paper. Without loss of generality, we first align the vector map with the satellite images by their GPS locations. Then only the road areas are extracted, on which the vehicle detectors are run. In such a way, “background” inference such as buildings is removed from the subsequent operations, which largely reduces the false alarm as well as improving the recognition speed.