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Classification-based vehicle detection in high-resolution satellite images

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ABSTRACT

In this study, we have looked into the problem of vehicle detection in high-resolution satellite images. Based on the input from the local road authorities, we have focused not only on highways, but also on inner city roads, where more clutter is expected. The study site is the city of Oslo, Norway. To do vehicle detection in these areas, we propose an automatic approach, consisting of a segmentation step, followed by two stages of object classification. In the process, we utilize multispectral images, panchromatic images and a road network. The approach has been tested on Quickbird images, and the results that are obtained have been compared with manual counts and classifications.

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1. Introduction

Information on vehicle location and movement is important for transport planning, accessibility analyses and traffic statistics. Monitoring of traffic is therefore an important task for the authorities. Current technology typically collects data by the use of *inductive loop vehicle detectors* embedded in (or lying on) roadways. This equipment provides traffic flow information over time for a point in space. However, other types of information from a larger area could often be useful to better understand the dynamics of the traffic. Images of a large road network could, for instance, be used to acquire information from a whole region at one point in time. Such snapshots of entire networks could give more insight into the distribution of vehicles in a region, and could also provide valuable information for areas not covered by traditional counting equipment. Until recently acquisition of such traffic snapshots has not been feasible, but since the launch of civil optical high-resolution satellite systems like Ikonos and QuickBird, images with a resolution of around one meter are now available. Hence, this type of imagery has a resolution that may make it possible to extract road traffic information.

In this study, we have looked into the problem of vehicle detection in high-resolution satellite images. Based on input from local road authorities, we will not focus only on highways, as has been done in a few other studies (Alba-Flores, 2005; McCord et al., 1998; Sharma, 2002; Sharma et al., 2006), but also on inner city roads, where more clutter is expected. The study site is the city of Oslo, Norway, where three different areas have been selected. Here, the roads will be narrower than typical highways, and more vegetation along the roads is expected. In addition, the high latitude of the study area affects the light conditions. To do vehicle detection in these areas, we propose an automatic approach consisting of a segmentation step followed by object classification, utilizing multispectral images, panchromatic images and road network information.

2. Background

The main methodological challenge is related to the problem of vehicle detection in high-resolution satellite images, where the resolution on the ground is low compared with the size of the objects sought for analysis. Compared with vehicle detection in aerial images, this poses special problems and will, for instance, make it more difficult to separate vehicles from other types of object such as trees, road markings etc.

For vehicle detection in aerial images, different approaches have been investigated (Hinz, 2004; Schlosser et al., 2003; Stilla et al., 2004; Toth and Grejner-Brzezinska, 2005; Zhao and Nevatia, 2001). In these images, the resolution is higher than in satellite images and typical vehicles have a length of 13–26 pixels (Zhao and Nevatia, 2001). Hence, more details of the vehicles are visible in these images, and many of the approaches used for detection have applied 3D models (Hinz, 2004; Schlosser et al., 2003; Stilla et al., 2004; Zhao and Nevatia, 2001). Detection rates are generally high at this resolution. Less work has been done on vehicle detection in satellite images, but a few studies exist and a few methods are suggested for analysis of the panchromatic images.

Sharma et al. (2006) detect vehicles on highways in 1-m resolution IKONOS images. Three different approaches are used: (i) attempts to maximize the separation between vehicles and road surface by the use of principal component analysis (PCA), and thresholding of one PCA band, (ii) uses a Bayesian Background

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Transformation (BBT) to classify pixels as stationary or dynamic, by comparing the image to a historic background estimate, while (iii) uses a gradient filter followed by thresholding, morphological operations and clustering to detect vehicle objects. For all approaches, filtering on size, orientation etc. of the resulting connected components is performed. The approaches have all been tested on US highways. Of the different approaches the BBT method is reported to show the best overall performance. This method does however require that a good quality background estimate exists, which can often be a problem to obtain automatically.

Alba-Flores (2005) detects vehicles on highways in IKONOS images using two different thresholding approaches (multiple thresholds and Otsu's method (Otsu, 1979)). The approach is limited to one-way highway segments, and it has been tested on highways in the US. The use of pattern recognition techniques is proposed to make the detection more robust, but has not been applied. Gerhardinger et al. (2005) propose an inductive learning approach (i.e. a learning by example approach — where the system tries to induce a general rule from a set of observed instances). The approach uses characteristics such as radiometry, size, position and pixel patterns to distinguish vehicles from other objects within the road segments and it has been tested for highways in Baghdad.

Leitloff et al. (2005) have looked at the specific problem of detecting queues in urban areas. Regions of interest derived from data fetched from a geographical information system (GIS) are used and vehicles are detected in Quickbird images within these regions of interest. Queues are extracted by detecting lines within these areas. Single vehicles are then detected within the extracted line (queue), by detecting points of minimum and maximum width along the line.

Most of these approaches have been tested on highways in open areas, while we need an approach that will work also for inner-city roads. Here more clutter is expected, and we have therefore focused on finding a classification-based approach to be able to distinguish vehicle objects from different types of clutter. For this reason, we also want to exploit multispectral information, which can help in separating vegetation from other objects.

We will perform vehicle detection and classification in Quickbird images. The panchromatic band of these images has a resolution of 0.6×0.6 m. This means that an average-sized vehicle of 1.7×4 m will cover 2.8 by 6.7 pixels. Multispectral bands have a resolution of 2.44 m. Hence, in the multispectral images an average-sized vehicle will only have a size of 0.7×1.6 pixels. In addition, there is a small time delay between the acquisition of the panchromatic and the multispectral image. This means that for moving vehicles, there will not be a correspondence between the position found in the panchromatic image and that found in the multispectral image. For actual vehicle detection we have therefore chosen to use the panchromatic band only. However, multispectral bands provide information which is useful, for instance, for distinguishing areas of vegetation from the road surface.

3. Methods

In the following we will describe the classification-based approach that has been developed. The approach consists of segmentation, feature extraction, pre-classification and a final classification.

3.1. Segmentation

3.1.1. Segmentation of vegetation

Trees shadowing the road can be a problem for vehicle detection, both because vehicles may be hidden behind the trees and because trees may be confused with vehicles. The first problem cannot be solved, but the second problem can be helped by segmenting trees (and other vegetation) by utilizing multispectral information. We have done this by computing the NDVI (normalized difference vegetation index) from the multispectral data. By thresholding the resulting NDVI image, the areas with vegetation can be identified and masked out.

From a multispectral Quickbird image, we have performed a resampling to the resolution of the panchromatic image using cubic interpolation. From the resulting image, NDVI was computed as: $(\mathrm{NIR}-\mathrm{R})/(\mathrm{NIR}+\mathrm{R})$. Otsu's method for threshold selection (Otsu, 1979) was then applied to the NDVI image to obtain a vegetation mask.

3.1.2. Segmentation of shadowed areas

For some parts of the road network, larger areas may be very dark due to shadows from tall buildings. These areas need to be identified and specially analysed. In this study, we have only focused on identifying these areas, while the problem of analysing the contents has been left to a later study.

To find the shadowed areas, we used the resampled multispectral Quickbird image obtained as described in the previous section. The four bands of this resampled multispectral image were then clustered into three clusters, using K-means clustering (MacQueen, 1967), where the cluster with the lowest mean value was selected as the shadow mask.

3.1.3. Segmentation of vehicles

For the segmentation of vehicles, we have, for reasons described above, used only the panchromatic image. The segmentation approach assumes that a definition of the road network to be analysed is available through a mask delineating this area. This can be derived from GIS data. The masks obtained through the analysis of the multispectral images are used to mask out areas within the road network corresponding to vegetation and dark shadows. For the area within the mask, the approach then assumes that the road surface is the dominating region covering the largest area within the mask. Based on this assumption, the histogram for the pixel values within the road network is analysed and the mean value of the road surface is determined at the peak of this histogram. Then Otsu's method for threshold selection is applied twice, once for the interval below this peak, and once for the interval above.

This approach results in a segmentation of the pixels into three categories: dark objects, road surface and bright objects. From this segmentation result, the connected components (connected pixels that have been given the same label) corresponding to the dark and the bright objects can then be identified. These components will then correspond to vehicles and to other similar objects such as smaller shadows, road markings etc.

3.2. Feature extraction

Segmentation will result in detection of different types of objects, where the objects corresponding to vehicles need to be identified. For this, we will use a classification approach, where specific characteristics (features) of the objects are first extracted from each object before the objects are classified based on these features. Two types of features have been used; *spatial* features describing the shape of the objects and *grey level* features describing properties related to the pixel values of the objects.

3.2.1. Spatial features

Spatial features were selected to be able to distinguish vehicles from other types of objects based on their shape. Vehicles are expected to be compact objects with a rectangular shape that have a width and a length within a certain size range and an orientation parallel with the road. Hence, different features that were expected to reflect these properties were tested. To select the initial set of these features we have built on previous experience from other projects on object recognition (see for instance Solberg and Solberg (1996)). The set of features that was selected is described below. Some of these features were only used in pre-classification, while others were only used for final statistical classification.

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