Vehicle detection from airborne images by separation of texture properties and their fusion

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Abstract

For the detection of vehicles from airborne images, obtained by a camera with disturbances in their uniform motion, different mathematical methods are combined. The stochastic motion, suddenly changes of lightening, the shadows, the different brightness depending of the angle of view etc. demand an isolation of obstacles from single images. This is mostly possible by analysing their texture, because this depends only weak on the changes of brightness. The textural properties are described by about a dozen of different functions, which have to be fused for a decision. For the description of textural properties fuzzy measures, fuzzy functions and fuzzy integrals are used. The regions of a selected property are generated by graph theory. The fuzzy integral is used to fuse properties of different kind and to generate generalised images, based on texture properties. The methods are successfully applied on different airborne images for isolation of vehicles and masking of bushes and trees, roofs of houses etc.

Keywords: fusion, airborne traffic detection, vehicle detection, detection of textures, graph theory

1 Introduction

For the detection of vehicles the cameras are mounted on airplanes, on helicopters or on a balloon (Zeppelin) for monitoring a larger region. From each image, different kinds of properties are isolated and then fused for new synthesised properties, which are better adapted for detection and characterisation of vehicles. The methods for detection are based on a separation and estimation of stochastic properties coupled with properties of partial brightness of regions within the image. All detected elementary properties of different kinds are used to obtain synthesised properties by measure and graph theoretical description for a better-adapted detection. For detection of extended regions for masking, a graph theoretical basis is developed. Different algorithms detect the dark and bright vehicles. Basis for the detection of vehicles is only a single image for a selected region or time.

2 Isolation of texture properties

The changes of lighting, shadows and day-night conditions are a problem for the detection of the traffic on the road. On the other side, the disturbances of the location of a balloon or the velocity of an airplane make ineffective the application of difference images. So, the background can be estimated only roughly by the texture. The textures, or mathematical spoken the stochastic properties, are robust against the change of the level of the grey values and independent of the motion of the camera. It is rather the near relationship of the neighbouring points, which describes these properties. The textures are often of stochastic kind, such as bushes, trees, microstructures of the road, structures of lawn, surface of plaster or roofs of houses. The polished surfaces of vehicles are a property to distinguish vehicles from the background.

The image consists of a set of points {i,j} with the grey values $x_{i,j}$. It is assumed, that regions of different texture exists. By a non-parametric algorithm different regions with hidden properties are isolated. The surrounding of a pixel-point x_{ij}, given by the 8 neighbouring points $x_{i-1,j}$, $x_{i,j-1}$, $x_{i+1,j}$, $x_{i,j+1}$, $x_{i-1,j-1}$, $x_{i+1,j+1}$, $x_{i-1,j+1}$, $x_{i+1,j-1}$ or a multiple of this set are compared by logical or arithmetical operations like signum-relationship $G_{i,j}$

$$G_{i,j} = \sum_{k=-m}^{m} \sum_{l=-n}^{n} \mathrm{sgn}(x_{i,j} - x_{i+k,j+l})$$

or difference-relationship $D_{i,j}$

$$D_{i,j} = \sum_{k=-m}^{m} \sum_{l=-n}^{n} abs\,(x_{i,j} - x_{i+k,j+l})$$

of point $x_{i,j}$ related to each point in this region. The central point of analysis $x_{i,j}$ is varied over the entire image, representing a relationship between short distance points. If the region is nearly uniform, then these values are small. They are big if the region is more varying over short distances. To distinguish different kinds of textures, several properties have to be considered. Such properties are the variance V

$$V_{i,j} = \sum_{k=-m}^{m} \sum_{l=-n}^{n} (x_{i+k,j+l} - m_{i,j})^2$$

with $m_{i,j} = mean(\{x_{i-n,j-m}, x_{i+n.j+m}\})$

or a function similar to the entropy [1]

$$I_{i,j} = - \sum_{k=-m}^{m} \sum_{l=-n}^{n} x_{i+k,j+l} \log_2(x_{i+k,j+l})$$

or the stochastic over different extended regions of 4*n*m pixel-points given by a difference of the original and a smoothed image

$$S_{i,j} = x_{i,j} - smooth(\{x_{i-m,j-n}\ x_{i+m,j+n}\})$$

Also the more determined properties, such as the periodicity, are used to discriminate different regions. For the periodicity the quotient of the grey value distance to the distance of the used pixel points is applied

$$P_{i,j} = \sum_{k=-m}^{m} \sum_{l=-n}^{n} \frac{x_{i,j} - x_{i+k,j+l}}{1+(k-l)^2} \quad .$$

With the property

$$K_{i,j} = histogram\left(\sum_{k=-m}^{m} \sum_{l=-n}^{n} abs(x_{i,j} - x_{k,l}) \right)$$

the texture represented within the contrast is extracted. For all properties the point (i,j) is moved over the entire image and generate a new synthetic image representing the distribution of this property.
Other properties can be obtained in an analogues way by the fuzzy ranking [2], the Lee-filter, wavelet-analysis, Gabor-filter and co-occurrence matrixes.

3 Fusion of different properties

For the description of the stochastic texture, the elementary texture properties, obtained by the above given relationship for G, D, V, S, I, P and K, are fused. By such a fusion the vehicles, trees, roads etc. can be better distinguished. The elementary properties are distributions on the pixel points and will be represented by measures. Because the textures are not to describe by simple functional relationships (exclusions and incompleteness are possible), fuzzy measures are applied. By the fuzzy measure, different kinds of elementary contributions are normalised and then mapped on the closed interval [0,1]. Some properties are more functional and better represented by fuzzy functions. Fuzzy functions are related to fuzzy measures and also map a property on the closed interval [0,1]. Such a representation is the basis for handling information if the knowledge is incomplete. In our case, a full knowledge is impossible, because the image contain stochastic information with a huge number of possible combinations. Many properties within an image are also hidden.
The elementary measure components $h(z)$ are coupled together represented by a coupling factor λ. The fuzzy elementary measure of the variable z (representing an elementary property in an area of the image) is introduced by Sugeno, 1974 [3] as:

$$h_\lambda(z_1 \cup z_2) = h_\lambda(z_1) + h_\lambda(z_2) + \lambda h_\lambda(z_1) h_\lambda(z_2)$$

The loss of additivity compensates the parameter λ obtained by the elementary fuzzy measures in the form

$$\lambda = \{1 + \lambda h(z_1)\}\{1 + \lambda h(z_2)\} - 1$$

For a set of elements $A = \{z_i\}$ the recursion gives by [3] :

$$h(A) = h\left(\bigcup_{i=1}^{n} z_i\right) = \sum_{i=1}^{n} h(z_i) + \lambda \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} h(z_i)h(z_j) + \cdots + \lambda^{n-1} h(z_1) \cdots h(z_n)$$

This non-linear equation for generation of a fused fuzzy measure $h(A)$ by elementary fuzzy measures $h(z_i)$ is solved approximately by an iterative calculation and gives for λ

$$1 + \lambda = \prod_{z_i \in A} (1 + \lambda h(z_i))$$

This non-linear equation for λ can be solved by iterative coupling of two properties z_l and z_m. This result is input for the next coupling of two properties. The fuzzy measure is adapted for properties representing closed regions. If the property is more functional, i.e. more described by singular values without stronger neighbouring relationships, then it is represented by a fuzzy function $q(z_k, h(z_k))$ over a region of a fuzzy measure $h(z_k)$.
Some example for representing properties as fuzzy measures are:

- Logical combination of bitmaps
- Estimated values of filtering
- Retransform of a wavelet representation
- Stochastic values obtained by the subtraction of original and smoothed values
- Fluctuations on the boundaries

Examples for the fuzzy function may be:

- Variations of values in different distances
- Changes of the stochastic of the grey values
- Differences of grey values in different directions
- Rank values related to different distances

The combination of two properties represented by a fuzzy measure and a related fuzzy function for generation of a new property is possible by fuzzy integrals. For this fusion, only parts of the properties are combined. The fuzzy integral of the old definition by Sugeno [3] is used, because it is well adapted to fuse properties on vehicles and surroundings. The fuzzy measure h is combined with the fuzzy function q by the fuzzy integral (written as a stylised f)

$$f_A q_\gamma(z) \oplus dh = \sup_{\gamma \in [0,1]} \left\{ \min \left[\gamma, h\left(A \cap Q_\gamma\right) \right] \right\},$$

$$Q_\gamma = \left\{ z \middle| q_\gamma \geq \gamma \right\}$$

Here, q_γ is the cut of q by the cut constant γ. For $q_\gamma(z)$ the fuzzy values over the area, given by the fuzzy measure h, are used. In the area A, all assumed properties and their combinations are collected. The result of the fuzzy integral fulfils the conditions for a fuzzy measure and a fuzzy function. Consequently, a new fuzzy function q_{γ_2} can be obtained from the fuzzy integral:

$$q_{\gamma_2} = \int_A q'_\gamma(z) \oplus dh$$

For the fuzzy measure, the relationship is analogue. Such new fuzzy measures and functions are the fundament for an iterative decomposition and creation of a new-composed property [4]. Otherwise, new components can be fused for more meaningful and sensitive properties. The stochastic properties are coupled with large-scale (non-stochastic) properties and then they are separated in their elementary parts. This is the fundament for a fusion of measures and related functions for a generation of composed generalised properties, better adapted to isolate cars, lorries, buses or pedestrians, from background of similar structure.

4 Estimation of the boundaries of regions with similar texture

For the separation of different texture regions a measure of the connection of neighbouring points is applied. This measure is given by knot connection. Such a measure of knot connection is used especially to find the boundary of a region defined by their texture. For the texture properties the coarse-grained stochastic properties are analysed. The connected regions of generalised images are analysed by the texture parameters, which are represented by a vector of properties or fused by a fuzzy integral.

The method for separation of a region B by texture within an image is based on the measure theory coupled with an adapted method of graph theory [5]. By such pre-processing a rough region with special texture is obtained. In the first step for isolation of a point within an expected middle of a region, a pyramid is used for contracting the contents of the image. If such a point within a region is found, the problem is now to extend this point or elementary region to find the boundaries of such a region with similar textures. The normal application of graph theory generates an exhaustive procedure, which is np-complete and cannot be used. Here, a method with a lower complexity will be used.

It is assumed, that in the pre-processing a point is found within a region where the searching can begin. A set of knots V may represent the pixel points in a surrounding region.

$$V=\{v_1, v_2, \dots, v_{n-1}, v_n\}$$

Between the vertexes of the knots different edges are possible of the form

$$E = \{e_1, e_2, \dots, e_{m-1}, e_m\}$$

The edges are directed connections between the knots. An edge between the knots 1 and 2 is defined by $e_{1,2} = [v_1, v_2]$. The edges contain values of the neighbouring points, given by the difference of the grey values or the difference of values of the related points within a generalised image. By this definition we can define a different inter-relationship on directed different ways. The way from a selected knot v_n to a knot v_m is going over a selected set of edges, i. e.

$$e_{n,m} = \{e_{n,1}, e_{1,2}, \cdots, e_{r-1,r}, e_{r,m}\}$$

The number of edges per knot is called the grad of the knot, thus $K_N(v_i)$ is the set of all neighbouring knots, also all knots, which are connected with the knot v_i. The neighbouring knots of a region B are called by $K_N(B)$ and given by

$$K_N(B) = \bigcup_{v_i \in B} K_N(v_i)$$

Boundary knots of B are called all such knots, for which is fulfilled

$$v_l \in K_N(B) \wedge v_l \notin B$$

Thus, boundary knots of a region B are given by

$$K'_N(B) = K_N(B) - B$$

Knots, which are member of two subsystems B and C, are called the cut knots K_s and given by

$$K_s(C,B) = K'_N(B) \bigcap K'_N(C)$$

For the optimal decomposition of the image, given by the knot system $K(V,E)$ in the subsystems $K_i(V_i,E_i)$ with $V_i \in V$ and $E_i \in E$, the following lemmas are used:

- The number of the knots of a subsystem is limited; number $\{V_i\} < N$.
- The number of the cutting knots is minimal, i.e. the interaction between the subsystems is minimal
- The interaction are calculated by non-parametric systems to give a measure for the magnitude of connection by a texture measure

By this graph theory, connection can be obtained by searching all possible connections fulfilling the similarity given by a threshold.
It may be assumed that the values W = $\{w_{i,j}\}$ (digital or integer values) characterise the texture region by method 1, the values Y= $\{y_{k,l}\}$ by method 2 and the values R = $\{r_{m,n}\}$ by method 3. The goal is, to select a region by interaction forces, where a selected texture is expected with the highest probability.
The interaction forces are calculated by a hierarchical application of non-parametric methods. It is assumed the grey values $y_{i,j}$ of the boundary for the extension are represented by the rank as followed

$$R_{i,j} = \sum_{l \in B} \sum_{k \in B} u(y_{i,j} - y_{k,l})$$

where $i \in B$ and $j \in B$ and $u(y)$ is the step function of the form

$$u(y) = \begin{cases} 0 & for\ y < 0 \\ 1 & for\ y \geq 0 \end{cases}$$

The values of the point (i,j) are member of selected area, if they are greater than a threshold g. The threshold for $y_{i,j} > g$ is determined by the quantile

$$\alpha = \frac{1}{\sqrt{2\pi}} \int_{\frac{2g-m}{\sqrt{\sigma}}} e^{-y^2/2} dy$$

Applying the threshold g, for the rank can be written

$$S_{i,j \in B}(g) = \sum_{l \in B} \sum_{k \in B} u(|y_{i,j} - g| - |y_{l,k} - g|)\ u(y_{i,j} - y_{l,k}) \quad (1)$$

Using for the step function

$$u(y) = \tfrac{1}{2} sign(y) + \tfrac{1}{2}$$

with $|y_{i,j} - g| \geq |y_{k,l} - g|$ for $y_{i,j} > y_{k,l}$

and $|y_{k,l} - g| \geq |y_{i,j} - g|$ for $y_{k,l} > y_{i,j}$

the upper relationship can be written as

$$u(y_{i,j} + y_{k,l} - 2g) = 1 \cdot$$

Using this relationship in equation (1) we obtain with the cut constant C for suppressing not essential contributions the relationship

$$S(y_{i,j}, g, C, B) = \sum_{k \in B} \sum_{l \in B} u(y_{i,j} + y_{k,l} - 2g) \geq C \quad (2)$$

With C can be suppressed noise without a relevant texture property. Different values of C can also be used to get an ordering of weak and strong interaction between the points. The formula (2) is faster to calculate than (1), because the two absolute values have not to be calculated. These results for each point are used as the information for extension given upon each knot. For the calculation can be used cloudlike regions or simple geometrical forms such as lines in different direction, rectangles, circle areas or pieces.

5 Applications

The ensemble of methods is used on airborne images mostly taken from Zeppelin or helicopter for traffic control. Different cameras, flight heights and flight days are used. In fig.2 is seen the masked area of trees of fig.1 obtained by extension of the region by graph theory. In fig. 3 the isolated vehicles are shown. In fig. 4 are shown the main roads and streets between family houses where vehicles are driving and parking. Different algorithms mask the trees and roofs as shown in fig. 5. In fig. 6 the dark and bright vehicles are represented which are detected and isolated in the image of fig. 4.

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7 References

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Figure 1: Original airborne image near the Brandenburg gate in Berlin with vehicles. The vehicles are bright and dark and also shadows are on the street.

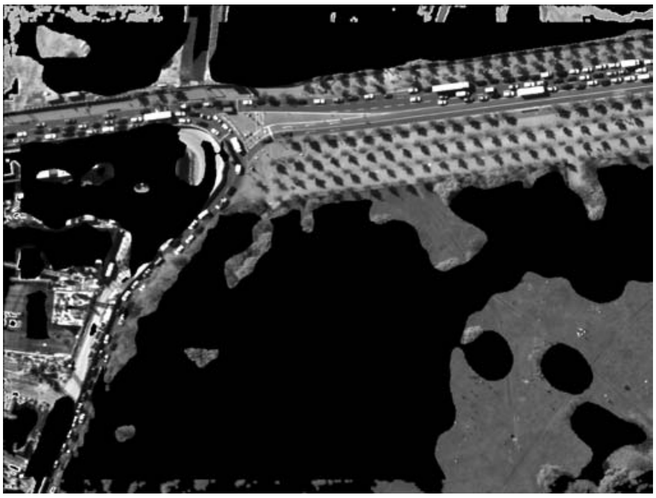

Figure 2: Trees and houses of Fig.1 are masked by texture properties. The oak trees are of other texture then the isolated trees near the street and so they are not masked by the applied procedure.

Figure 3: Bright and dark vehicles of image of fig. 1 are isolated and represented by white areas

Figure 4: Image from balloon (Zeppelin) with traffic on the road

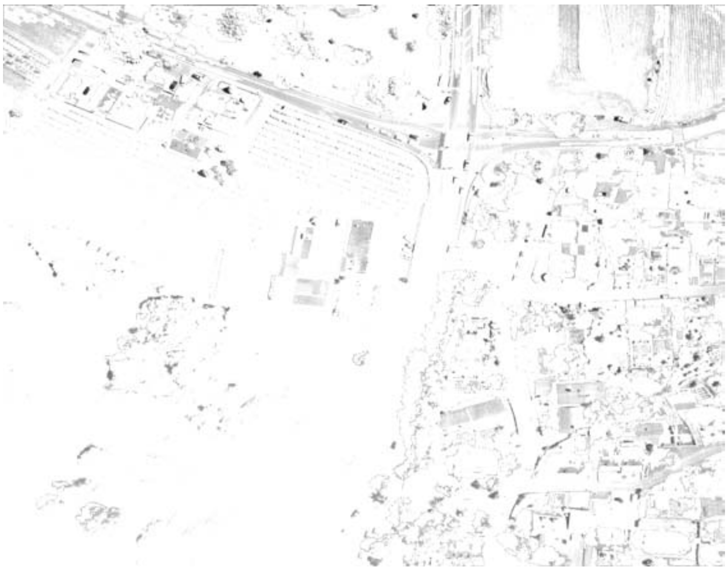

Figure 5: Separation of roofs, trees, bushes and lawn by texture analysis of image of fig. 4

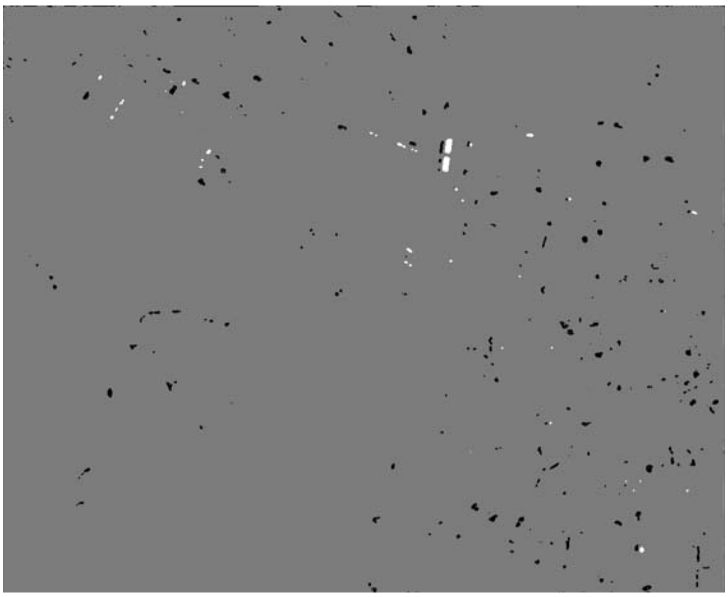

Figure 6: Bright and dark vehicles detected in image of fig. 4.