Characterisation of Clouds and Their Heights by Texture Analysis of Multi-Spectral Stereo Images

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ABSTRACT

Non-linear filtering and representation of singular values by a Lebesgue measure and Lebesgue integral create the values to characterise different properties. Fuzzy measures and fuzzy functions represent these different types of properties, stochastic as well as non-stochastic. This is the basis for their fusion by fuzzy integrals for the characterisation of clouds and estimation of their boundary. The boundaries of the clouds are described by parameter functions obtained by fuzzy curve analysis in different directions. Such functions characterising the boundary are generated for different spectral images. This is used for characterising points for matching and finding similarity of parts of the clouds for stereo matching and estimation of the heights of clouds.

VALUES FOR CLOUDS REPRESENTED BY LEBESGUE MEASURES AND CHARACTERISED BY FILTERING

Mostly, the clouds are diffuse and boundaries are difficult to generate. For the comparison of related regions in stereo images with clouds exists the problem that the form of the clouds dependent on the different angle of observations necessary for stereo images. If the second stereo image is taken with a time lag, e.g. by airborne or space borne observations with a line camera, then by the dynamic in the clouds also the form of the clouds can be changed. Another problem exists for the boundary, if one pixel locks at the cloud and the neighbouring pixel locks at the landmass surface or locks partially at the cloud and the surface. In this case the values are unsteady, i.e. isolated points in mathematical sense. The most points on the boundary of the clouds are such isolated points, so that a point measure has to be used. Moreover, the information within the clouds is better described by their texture than by edges or skeletons. The texture has to be described very precisely by using all available information. This is possible by description and estimation of their stochastic.

Therefore, the correlation analysis for detection of corresponding points in clouds is problematically and will be extended here by application of point measures and non-linear filtering. Subtraction of expectation values from measured values and estimation of stochastic parameter fields obtain the stochastic structures of the cloud boundaries. The stochastic structures of the boundary are then the basis values for the determination of corresponding points and corresponding contours of clouds for a decision making by fuzzy integrals. In the case of unsteadiness the normal function raises difficulties and a point function is more adapted. This is well described by the Lebesgue measure [1].

The rough contours of the clouds are found by labelling of regions and isolate all with clouds by properties such as changing brightness against the surrounding pixels beginning from the centre and special textures. The changing of properties on lines in different angles beginning from the centre of clouds are the bases for the extraction of boundaries within the clouds. For the calculation of the fine structure of the boundary of the clouds are constructed an inner contour where the points are within the clouds and an outer contour where the points are outside the clouds. The contours are represented by a larger number of points. The points of the inner and the outer contour are connected and give lines or intervals of points crossing the boundary in different directions. Every point of the interval represented by two coordinates is related to a set of functional values of stochastic and other values describing the nearest neighbourhood of the point. The properties are measured on the open elementary interval \( a_k - b_k \), where \( a_k \) is the initial point and \( b_k \) is the endpoint of the interval \( k \). These contour points are related to the geometrical content \( |i| \) of the lines between the inner and the outer contour

\[
|i| = \prod_{k=1}^{n} (a_k - b_k) = \sum_{i=1}^{n} (-1)^i (c_1, \ldots, c_i)
\]  

where \( c_i = a_k \) or \( c_i = b_k \). On these contours point functions \( f(i) \) are defined by

\[
f(i) = \sum_{i=1}^{n} (-1)^i f(c_1, \ldots, c_i).
\]  

For \( i = 2 \) \( f(i) = f(b_1, b_2) - f(b_1, a_2) - f(a_1, b_2) + f(a_1, a_2) \) is obtained by (2). As a function \( f \) can be used e.g. the set of all points of a region given by a Borel measure \( B \), fulfilling the condition \( f > const \). The rules are determined by the importance of a property, so that e.g. \( 0 > \infty = 0 \). For all points of a measure along the boundaries different kinds of properties are collected in functions describing the boundaries. Because the number of points with unsteadiness characterised by the surrounding region is very high, the combination of the values has to be simple, so as logical connections. The function on the Lebesgue measure in form
of jump functions are combined with the Lebesgue point measure by the L-integral over the Borel set $B$ of points

$$
\int_B \phi(i) di = \int F(B, \varphi) \, dL.
$$

(3)

The Lebesgue integral is built by a segmentation of the jumps of the co-ordinate (grey) values and is not based on the pixel distance on the ordinate. Therefore, the effect of unsteadiness of the values along the boundary is suppressed. The Lebesgue integral values are the basis for a new image representing the boundary by steady values. If multi-spectral images exist, then differences of selected multi-spectral images enhance the boundaries of clouds. On the basis of the textures of the clouds, a better estimation of the boundary of the clouds can be found. For this, the small fluctuations have to be separated and analysed. For this analysis, the components have to be mathematically described as a coupled system of equations.

The different superposed kinds of elementary textures of the clouds are represented by a system of stochastic differential equations. The number of equations, the non-linearity and the clouds are represented by a system of stochastic differential equations with the gain factors $G_{s1}, \ldots, G_m$ of the noise describe the stochastic effects. For the coupled system of equations can be written

$$
d_y(x) = F_i(y_i(x), y_2(x), \ldots, y_r(x)) \, dx
$$

$$
d_y(x) = F_i(y_i(x), y_2(x), \ldots, y_r(x)) \, dx
$$

$$
d_{st1}(x) = F_{st1}(y_1(x), \ldots, y_s(x)) \, dx + G_{st1} \, n(x)
$$

$$
d_{stn}(x) = F_{stn}(y_1(x), \ldots, y_s(x)) \, dx + G_{stn} \, n(x).
$$

(4)

The matrix $F$ describes the non-linear function, e.g. exp for short and square root for long distance interaction. With the help of the martingale technique [2], which gives better understanding of the effect of approximation, expectation values of (4) are obtained. The number of equation and the gain of the noise are optimised by an adaptive process. The number of equation is incremented until the effect of changing is under an assumed threshold. For the stochastic is assumed that all components can be produced by white noise.

The coupling of equations produces the coloured noise. The stochastic components are obtained by subtraction of the expectation values from the grey values of the used image. These procedures are applied on images obtained by different procedures for generation. Non-parametric algorithms such as sign or rank algorithms also create stochastic properties. These different kinds of properties are combined for a better characterisation of the cloud boundary. This is possible by mapping of properties on a fuzzy measure or fuzzy function and a fusion of both by fuzzy integrals.

**REPRESENTATION OF PROPERTIES BY FUZZY MEASURES AND FUZZY FUNCTIONS**

For the comparison of corresponding points in stereo images, the points have to be characterised by a lot of properties describing the point of the image based of the relationship to the surrounding region. These properties are of different kind and have to be mapped on the same measure for comparison and superposition. This is possible by the fuzzy measure, which maps the properties on the closed interval $[0,1]$. By such a description, their ensemble of values, represented in a comparable manner, can compare singular points of stereo images. On the other side, functional similarities represented over parts of the boundary of clouds can be compared for matching. For singular points, properties can be used such as rank or sign algorithms also create stochastic properties. Otherwise, fuzzy measures for corresponding points on the boundary can be described by a curve obtained by projection of the contour on an axis. The different functional values over such curves are the basis for comparisons of properties over contours. The properties of a curve can be described by the steadiness of curves, height, width and rising of maxima, intervals between extrema, changing of higher derivations of a curve, short periodicity obtained by Walsh functions, and gradients for parts of the curve defined by features. Because the knowledge of all properties is not possible, the normalisation as demand by the probability theory cannot be used. The fuzzy measure does not need the complete knowledge of all properties by loosing the additivity. The benefit is that the importance of a property is considered. The fuzzy measure is used by the definition of Sugeno [3]. A coupling between the components represents the interconnection of both. By a coupling factor $\lambda$, the fuzzy measure (densities) $g(z)$ are combined by

$$
g_{kl}(z_1 \cup z_2) = g_{kl}(z_1) + g_{kl}(z_2) + \lambda g_{kl}(z_1) g_{kl}(z_2).
$$

(5)

Here, $\lambda$ calculated by $\lambda = (1+\lambda \, g(z_1)) \, (1+\lambda \, g(z_2)) - 1$ is used as a substitution for the loss of additivity. So, different elementary properties given by the set $(g(z_i))$ over the curve can be represented by a fuzzy measure. For a set of elements, $A = \{z_i\}$ (5) can be used recursively and gives

$$
g(A) = g(z_1) + \lambda g(z_1) \sum_{i=1}^{n-1} g(z_i) g(x_i) + \lambda^{n-1} g(z_1) \cdots g(z_n).
$$

(6)

Such a representation of properties is also possible for fuzzy functions $h(z)$. The fuzzy functions are related to special fuzzy measures and represent the composed properties over contours. For the fuzzy function properties are used such as: differences of data values for related distances, stochastic changes of values in neighbouring areas and in different directions, number of ranks related to different point
distances, and values obtained by wavelet transforms over a small distance. The fuzzy functions maps the information also in the interval [0,1] and gives together with the fuzzy integral new kinds of decompositions for better decision making.

**FUSION OF PROPERTIES BY FUZZY INTEGRALS**

The fuzzy integral of the old definition of Sugeno [3] will be used, because it is well adapted to fuse properties on contours. The fuzzy measure \( g \) is combined with the fuzzy function \( h \) in the form (written as a stylised \( f \))

\[
\int_A h_a(z) @ dg = \sup_{a \in [0,1]} \{ \min [a, g(A \cap H_a)] \}, \quad H_a = \{ z | h_a \geq \alpha \} \tag{7}
\]

Here, \( h_a \) is the cut of \( h \) at the constant \( \alpha \). For \( h_a(z) \) the fuzzy values over the boundaries given on the elementary part \( g \) are used. The threshold \( \alpha \) fulfils the assumption that only properties under limited conditions have an effect. The area \( A \) is the collection of all assumed properties and their combinations. The result of the fuzzy integral fulfils the conditions for a fuzzy measure and a fuzzy function. Consequently, a new fuzzy function \( h_{a_2} \) can be constructed from the fuzzy integral:

\[
h_{a_2} = \int_A h_{a_1}^*(z) @ dg \tag{8}
\]

For the fuzzy measure the relationship is analogue. By such construction of a new fuzzy measure and function, an iterative procedure is constructed for an iterative decomposition of properties [4]. Otherwise, by (7) and (8) new components can be fused to new properties, which may be more meaningful and sensitive for the description of properties for comparison in stereo images. By an iterative procedure, vectors of 'synthetic' values to characterise especially the points within clouds and on the boundary are generated. By using an adaptive control, most stochastic properties are separated. This is done for all points. So, the corresponding points are found by comparing of the property vectors for such points, which are within the distance of the assumed maximal disparity.

**APPLICATIONS AND RESULTS**

The shown algorithm is applied on ATSR2 and MOMS images to find cirrus clouds and contrails. Other types of clouds and the earth surfaces are detected and isolated by their texture and their hights, where the precise determination of the boundaries is important for finding related stereo points. In Fig.2 are three boundaries visible, for the description of cirrus clouds with very blurred contours. By the analysis of texture properties, the kinds of clouds and their heights could be estimated successfully.

**REFERENCES**