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TEXTURAL ANALYSIS BY STATISTICAL PARAMETERS AND ITS APPLICATION TO THE MAPPING OF FLOW-STRUCTURES IN WETLANDS

(MUDFLAT AREA AT THE GERMAN COAST OF THE NORTH SEA)

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ABSTRACT

For mapping the morphology in mudflat areas a digital texture analysis has been developped, by which measurement of the change of image-structures caused by disturbing factors like changing illumination will be possible.

1. INTRODUCTION

From 1974 until 1977 the application of remote-sensing methods in coastal areas and tidal bays and estuaries was investigated on the German coast of the North Sea. The Institute for Geography at the University of Munich, Section Remote Sensing, with its leader Prof. H. G. Gierloff-Emden took part in the investigations at the Jade in the north of the town Wilhelmshaven.

Responsible for the technical performance of these investigations was the DFVLR (Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt). Aerial photographs were taken using different films: color, color-infrared, black- and white films. Scanner-recordings were taken by an 11-channel-scanner (Bendix). Groundtruth-measurements of radiation and measurements of meteorological elements were carried out.

The task of the Institute for Geography at the University of Munich was to investigate how the change of morphologic phenomena can be recognized by application of methods of remote sensing and technics of image-enhancement. The investigated phenomena, described in this paper are flow-structures like banks and ripples. These structures are dependent of the grain-size of the sediment, the velocity of the streaming water and the shear-stresses.

Significant change of those structures can be caught hold of remote-sensing systems. To find out the reason of such changes ground-measurements have to be made. Together with groundtruth measurements on some suitable points the change of the conditions causing these structures can be mapped.

2. DISTURBING FACTORS WITH MAPPING FLOW STRUCTURES IN THE MUD-FLAT

Two images of the morphology of a mud-flat surface can be very different though there can be no difference in the surface of the mudflat at the two moments when the surface is recorded by the remote-sensing system.

When mapping the morphology of the mud-flat by that errors in the interpretation are possible. So it is necessary to investigate the most important disturbing effects, which are influencing the image of the mudflat-morphology taken by a remote-sensing system.

These effects are in detail the following:

1. The effect of different illumination
   a. caused by the amount of the angle between the line joining the object on the earth surface and the plane and the line which coincides with the direction of the maximal reflection of the object, where sun elevation is always the same,
   b. caused by the different sun elevation.

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These effects can be called as geometric disturbing effects.

2. The effect of changing the reflectance by the draining of the puddles on the mudflat by flowing off of the water and by drying up by evaporation.

This is a disturbing factor due to the object.
Because of these disturbing factors for morphologic interpretation of mudflat-images it is necessary to take a sequenc with short time intervals, because the image of the morphology is a function of the dynamic process of the tides. To find out the change of the morphology during some weeks comparing of such two sequences of images is necessary.

There is now the question whether such disturbing factors can be eliminated or whether the disturbing factors are so characteristic, that identification of different types of ripple fields or bank fields is possible.

Therefore groundmeasurements of reflected radiation in the visible were made. Because of the problem of transportation exact measurements of radiation in different channels were not possible. The purpose of the measurements was the investigation of the reflectance of some little certain areas in bank and ripple fields in the mudflat in relation to different sun elevations. At each point measurements were made orthogonal down, 30° away and 30° against the sun. For each tested area characteristic differences of reflectance for the morphologic forms and the water puddles between them were found out. The differences changed that depends whether one have measured against the sun orthogonal down or with the sun. The reflection of the forms not covered with water was different and dependends on the relief of the forms. Difference of reflection between the forms and the water puddles is normally so strong that inspite of loss of information an image structure is caused. The structures in images showing the same areas can be different because of the influence of the disturbing factors. These factors are determinated by the reflection of the natural surface. Differences of this reflection dependent on sun elevation and the direction of measuring can be exactly found out on the ground. Differences in the image structure dependent on the factors 1., 2.a. and 2.b. can be quantitatively described only by a quantitative analysis of the image structure showing the interesting morphologic phenomena.

3. A METHOD OF TEXTURAL ANALYSIS FOR MORPHOLOGIC MAPPING WITH PARAMETERS DUE TO THE IMAGES OF THE SINGLE OBJECTS FORMING THE TEXTURE

3.1. TEXTURAL PARAMETERS

For solving the problem explained before the image structure has to be described by parameters which are connected with properties of the images of the single objects. So a description of the density-function D (x, y) by a Fourier transformation is not convenient. There is the problem how to correlate the Fourier-coefficients with morphologic parameters.

Morphologic parameters in this case are e. g. length, height and width of banks or larger ripples or such forms, which can be identified in an image by texture. Because the image of an object cannot be identified exactly in such a case the image-object is defined in the following way: For each image-point the difference between its density-value and the mean of the density of this point and 8, 24, or 48 points around it is computed. So the density-plane of the whole image is cut with a smoothed density-plane. The complete areas consisting of pixels for which the difference between the density of the original image and the smoothed image is greater 0 should be called as "image-objects", the areas for which this difference is less 0 should be called as complementary image-objects.

If the density of each point of the smoothed image is computed from 9 points more little image-objects or complementary image-objects are received than the density of each point of the smoothed image is computed from 25 or 49 points.

The density of each image object is caused by the radiation reflected or emitted from the earth surface. So an image-object correlates with an object or a part of an object on the earth surface.

Are those objects banks or greater ripples the correlation is quite good and parameters of the image objects and the complementary image-objects are in relation with morphologic parameters.

So the first group of textural parameters consists of the following parameters:

I) Distribution of the amount of the area, of the relation circumference/amount of area and of the length coefficient of the single image-objects of an image section. The length-coefficient is the linear correlation coefficient of the set of points belonging to one groundplan area of an image-object. In connexion with the computation of the correlation coefficient the direction of the correlation line is computed.

Characterizing the average form of the image objects in the direction of the density axis (D (x, y)) the group of the following parameters is computed:

II) The distribution of the gradient vector (dD/dx, dD/dy, 1) in the x, y-plane. The distribution of the gradient vector shows whether the variance of the density-values is high (the length of the gradient is large) or low (the length of gradient is small). Secondly one is interested in favored directions of the gradient vector. In supplement to this distribution the correlation coefficient and the direction of the correlation line for the group of points destined by the gradient vector is computed. To avoid mistakes 1 % of these points, these are the points for which the gradient vector has the greatest amount, are omitted. If the main direction of the gradient-vector and of the correlation-line are nearly the same, there would be in the image longer line-elements with high contrast otherwise, if the correlation line is orthogonal to the favored direction of the gradient-vector, there are no or only very short line-elements of higher contrast in the analysed image-section. In connection with the length of the gradient-vector and the size of the image objects is the distribution of the curvature of D (x, y). The curvature can be computed in different ways, one of them is the computation of the La Place differential expression $d^2D/dx^2 + d^2D/dy^2$. Another possibility is to compute the mean of the angles between the tangential plane and D (x, y) in a certain point, where for each point the angles are computed in 8 directions. If the angle is large the banks or ripples have a stronger relief.

At last the arrangement of the image objects in the aerial photograph or in the scanner-image has to be described:

III) For that the shortest distance between the main point of each two objects has to be destined. The distribution of these distances and the distribution of the direction of these distances correlates with the distribution of the shortest distances of each two banks and the distribution of the direction of these distances.

It is notable that the textural parameters are not characterized by numbers but by distributions except the correlation coefficient and correlation line in II. Characterizing the textures only by numbers is only possible by describing the distributions by their statistical parameters as mean and standard deviation. Loss of information can be avoided only, if the texture has a very regular structure.

3.2. THE PROBLEM OF INVARIANCE AGAINST ROTATION

The problem is that, if a texture analysis is made for two images, it is difficult to compare the results of the analysis, also if the same film was used. Differences in the results are not only caused by disturbing factors as described in 2. and other disturbing factors as different devellopping of the film, but caused by changing the scan direction when the image is digitalized. So all directions computed in I), II) and III) are dependent on rotation. But the effect of rotation can be eliminated very easily. For the remaining parameters invariance against rotation is very important. Change of the scanning direction causes changes of the scanning pattern. Because the scanning is rectangular, exact invariance against rotation is not possible. But for the parameters described in I) and III) the change, caused by rotation of the scanning direction is not significant if the solution of the scanning is high enough.

To compute the gradient-vector in an image-point (x, y) it is normally sufficient to draw on for the computation the 8 points around (x, y). In extreme cases the rotation of the scanning direction causes differences of the length of the gradient, which have the factor SQRT(2). In practical performance, when contrast is not extremely high the errors caused by rotation are not significant. The formula for the computation of the gradient is:

$$\mathrm{grad}(x_o, y_o) = \mathrm{nabla} \cdot D(x, y) = (dD/dx, dD/dy, 1) = (s\dot{x}_o, s\dot{y}_0, 1)$$

with

$$s\dot{x}_o = ((sx_{-1,1} - sx_{1,-1}) + 2 \cdot (sx_{-1,0} - sx_{1,0}) + (sx_{-1,-1} - sx_{1,1}))/4$$

$$s\dot{y}_o = ((sx_{1,-1} - sx_{-1,1}) + 2 \cdot (sx_{1,0} - sx_{-1,0}) + (sx_{1,1} - sx_{-1,-1}))/4$$

where the points (x_i, x_j) are arranged in the following way:

$$\begin{array}{ccc} x_{-1,1} & x_{0,1} & x_{1,1} \\ \cdot & \cdot & \cdot \\ x_{-1,0} & x_{0,0} & x_{1,0} \\ \cdot & \cdot & \cdot \\ x_{-1,-1} & x_{0,-1} & x_{1,-1} \\ \cdot & \cdot & \cdot \end{array}$$

The La Place expression is computed to:

$$s\ddot{x}_o + s\ddot{y}_o ,$$

where in the first equation above sx must be replaced by $s\dot{x}$ and in the second sy by $s\dot{y}$.

In exceptional cases a better approximation for computing the gradient is necessary. 21 points have to be drawn on, which are arranged in the following way:

$$\begin{array}{ccccc} & \cdot & \cdot & \cdot & \\ \cdot & \cdot & x & \cdot & \cdot \\ \cdot & x & \cdot & x & \cdot \\ \cdot & \cdot & x & \cdot & \cdot \\ & \cdot & \cdot & \cdot & \end{array}$$

The computation of the gradient is done in the same way as before, only 9 points are needed for the computation, but the density of the 4 points marked with x is the mean density of these points and the 8 points around them.

3.3. PRACTICAL PERFORMANCE OF THE TEXTURAL ANALYSIS

For practical performance of this digital texture analysis the image information must be recorded on a CCT. This is no problem for scanner-images, which are normally recorded on a CCT. Aerial photographs can be written on a CCT by a photoscan (e.g. Optronics). At the Optronics Photoscan a width of the scanline of as $12.5 \cdot 10^{-6}$ m, $25 \cdot 10^{-6}$ m and $100 \cdot 10^{-6}$ m can be chosen. To avoid optical rustling it is suitable to scan with $100 \cdot 10^{-6}$ m, that is a solution of 10 lines/mm. For a Zeiss-RMK-photograph the density-values of 5,290,000 image points have to be written on the tape at a solution of 10 lines/mm. As a rule it is not necessary to analyse the texture for a whole image. There are only some areas of interest. The coordinates of their corner-points have to put in into the computer and the texture analysis for the appropriate section is made. It is possible to panel this section in several smaller sections for which the analysis should be made. An analysed section cannot have more than 10,000 image points for the capacity of the CPU-storage for one job at the Leibniz-Rechenzentrum in Munich is only 100 K. So at a solution of 10 lines/mm the largest of a section which is not panelled is 1 cm^2. If the solution is only 5 lines/mm this section may have a size of 4 cm^2.

If the parameters of two sections are nearly the same, then the textures would be nearly the same.

For computing the textural parameters two computer programs were written, one in ALGOL and the other in FORTRAN. The FORTRAN-program is about thrice faster than the ALGOL-program. But by the possibility of defining variable array-fields the image-sections for which the parameters should be computed can be selected quite variable and CPU-storage can be spared. If a digital image-analysing-system has a computer, which is as fast as the cyber 175 (Control Data), the image shown on a television screen can be analysed during a CPU-time during between 5 and 9 minutes, where the whole image shown on the screen is divided in 25 sections. If a section has a texture of low frequency the parameters for much less image objects have to be computed so that then the analyse is faster than if the frequency is high.

4. TEXTURE TYPES FROM THE MUDFLAT

After developping the program by which the textural parameters are computed, the task is now to analyse the disturbing factors explained in 2. These investigations are not yet finished. So in the following two only little different texture-types in two sections belonging to the same panelled section (Fig. 1). The distance between the central points of the two sections is about 70 meters. The image section which is pannelled shows the border-area of a tidal creek. The region shown in section 1 lies about 0.5 meters deeper than the region shown in section 2. The original aerial photograph is a color-infrared photograph. The photograph was taken at August the 11[th] 1976, at 8.58 hours in the morning, two hours after low water.

On the area shown in section 1 more water was on the mud as on the area shown in section 2. This fact can be ascertained by the parameters of the group I.

The textural parameters for the two image sections 1 and 2 are the following:

SECTION 1:

GROUP I:

a. IMAGE OBJECTS: TOTAL: 201

i. AMOUNT OF AREA

162	20	8	4	3	1	1	1		1		
0 – 10	10 – 20	20 – 30	30 – 40	40 – 50	50 – 60	60 – 70	70 – 80	…	180 – 190		pixel

mean: 7,49751 standard deviation: 16.74721

ii. RELATION CIRCUMFERENCE/AMOUNT OF AREA

		2	13	15	21	12	24	7		23
1 – 1.2	1.2 – 1.4	1.4 – 1.6	1.6 – 1.8	1.8 – 2.0	2.0 – 2.2	2.2 – 2.4	2.4 – 2.6	2.6 – 2.8	2.8 – 3.0	3.0 – 3.2

0	0	0	85	
3.2 – 3.4	3.4 – 3.6	3.6 – 3.8	3.8 – 4.0	circ./am. of area

mean: 3.02622 standard deviation: 0.89995

iii. LENGTH COEFFICIENT

0	1	0	89	6	8	7	5	8	9	12	17	39		
−1.0	−0.2	−0.1	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	corr. coeff.

mean: 0.3953 stand.dev.: 0.40749

The mean of the direction of the correlation line is 25.6°, the standard deviation is 22.7°.

b. COMPLEMENTARY IMAGE-OBJECTS TOTAL: 123

i. AMOUNT OF AREA

90	15	6	3	4	0	1	0	0	1	1	0	0	1	1	0	
0	10	20	30	40	50	60	70		120	130	140		230	240	250	pixel

mean: 13,98374 standard deviation: 34.61753

ii. RELATION CIRCUMFERENCE/AMOUNT OF AREA

0	0	5	16	9	15	9	10	8	0	14	0	0	0	0	37	
1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	circ./am. of area

mean: 2.75949 standard deviation: 0.90217

iii. LENGTH COEFFICIENT

0	1	1	40	6	4	5	4	3	8	5	11	35	
−1.0	−0.2	−0.1	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0

mean: 0.48402 standard deviation: 0.41442

The mean of the direction of the correlation line is 28.7°, the standard deviation is 24,0°.

GROUP II:

i. LENGTH OF THE GRADIENT VECTOR

455	963	795	563	334	166	57	13	3	4	0	1	1	0	2	0	0	3	1	0	
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

1	0	1	1		
20	21	22	23	24	$\cdot 10^{-1}$ mm

mean: 2.65101 standard deviation: 1.70299

ii. DIRECTION OF THE GRADIENT VECTOR

116	139	88	100	170	95	96	99	52	120	99	59	49	142	
−180	−170	−160	−150	−140	−130	−120	−110	−100	−90	−80	−70	−60	−50	−40

69	73	87	45	170	113	91	104	187	107	95	88	112	52	85	46	64	95	52	
−40	−30	−20	−10	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150

73	74	58		
150	160	170	180	(°)

mean: −103,5° standard deviation: 51,0°

iii. CURVATURE ANGLE

1	0	9	28	45	61	55	75	82	108	109	128	117	148	153	
−180	−170	−160	−150	−140	−130	−120	−110	−100	−90	−80	−70	−60	−50	−40	−30

182	167	144	205	189	172	152	192	135	151	115	121	93	73	62	48	26	12	5	0	1	
−30	−20	−10	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180 (°)

mean: 0.2° standard deviation: 68.3°

iiii.
correlation coefficient −0.99797
direction of correlation line: −0.096°

GROUP III.

i. SHORTEST DISTANCES BETWEEN THE OBJECT IMAGES

4	50	81	49	15	1	1	
0	1	2	3	4	5	6	7

mean: 2.58133 standard deviation: 0.87958

ii. DIRECTION OF THE SHORTEST DISTANCES

6	13	14	7	22	10	4	10	8	11	10	15	8	22	11	7	11	2	10	
−90	−80	−70	−60	−50	−40	−30	−20	−10	0	10	20	30	40	50	60	70	80	90	(°)

mean: −1.5° standard deviation 51.7°

SECTION 2:

GROUP I:

a. IMAGE OBJECTS TOTAL: 144

i. AMOUNT OF AREA

116	15	2	4	3	0	1	0	0	1	1	0	1		
0	10	20	30	40	50	60	70	80	90	100	110	490	500	pixel

mean: 11.0625 standard deviation: 42.84034

ii. RELATION CIRCUMFERENCE/AMOUNT OF AREA

0	13	9	14	12	10	11	0	19	0	56
1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	4.0	

mean: 2.98244 standard deviation: 0.88687

iii. LENGTH COEFFICIENT

0	56	0	10	78
0	0.1	0.8	0.9	1.0

mean: 0.58993 standard deviation: 0.47190

The mean of the direction of the correlation line is 27,5°, the standard deviation is 21.9°.

b. COMPLEMENTARY IMAGE OBJECTS: TOTAL: 152

i. AMOUNT OF AREA

102	28	8	4	4	0	3	1	1	1		
0	10	20	30	40	50	60	70	80	90	100	PIXEL

mean: 10.91447 standard deviation: 16.01359

ii. RELATION CIRCUMFERENCE/AMOUNT OF AREA

0	2	10	23	10	20	8	14	9	0	16	0	40
1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	4.0	

mean: 2.64037 standard deviation: 0.91308

iii. LENGTH COEFFICIENT

40	0	12	100	
0	0.1	0.8	0.9	1.0

mean: 0.70945 standard deviation: 0.42576

The mean of the direction of the correlation line is 33.2°, the standard deviation is 19.8°.

GROUP II:

i. LENGTH OF THE GRADIENT VECTOR

339 1007 892 636 306 117 54 4 3 0 2 3 0 1

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 $\cdot 10^{-1}$mm

mean: 2.60724 standard deviation: 1.35432

ii. DIRECTION OF THE GRADIENT VECTOR

123 104 97 125 156 111 98 108 53 128 76 54 62 111 61 50 93 59 164 114

−180 −170 −160 −150 −140 −130 −120 −110 −100 −90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20

105 133 150 115 111 98 110 44 79 65 56 120 49 59 79 44

20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 (°)

mean: 77,0° standard deviation: 50.4°

iii. CURVATURE ANGLE

0 0 1 8 33 47 65 85 105 113 122 139 124 154 153 175 170 135 193 176 203

−180 −170 −160 −150 −140 −130 −120 −110 −100 −90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20 30

165 155 127 152 133 118 94 75 56 42 29 11 3 2 1

30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 (°)

mean: 0.2° standard deviation: 67.2°

iiii.
correlation coefficient: 0.92443
direction of correlation line: 0.14285°

GROUP III:

i. SHORTEST DISTANCE BETWEEN COMPLEMENTARY OBJECT IMAGES

Because the number of complementary object images is greater than the number of object images, the shortest distance between the complementary object images is computed.

0 19 53 53 16 6 5

0 1 2 3 4 5 6 7 $\cdot 10^{-1}$mm

mean: 3.14186 standard deviation: 1.20905

ii. DIRECTION OF THE SHORTEST DISTANCES

9 13 10 5 13 11 4 6 14 8 6 5 13 5 4 6 14 2 4

−90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20 30 40 50 60 70 80 90 (°)

mean: 1.47968 standard deviation: 52.44994°

There are differences between the parameters of group I. The scanned aerial photograph was a color infrared negative. So water has very low density values and correlate with the complementary image objects. The image objects correlate with the banks. In section 1 there are more image objects than in section 2 and less complementary image-objects than in section 2. The area shown in section 1 lies deeper and nearer to the tidal creek as the area shown in section 2. On the mudflat of section 1 the quantity of water is greater, the part of the banks which do not ly under water are smaller than on the mudflat in section 2. In section 1 the banks are more isolated and many water puddles are joined together, so that the number of complementary image-objects is smaller and the complementary image objects are greater on the average. The length coefficient for section 2 is nearer to 1 because little creeks orthogonal to the banks are formed. For the parameters of group II there is only a difference for the direction of the gradient. This difference is about 180°. This difference is probably caused by a stronger inclination of the surface shown in section 1 to the sun (to the right in fig. 1), so that the effect of shadow is stronger in section 2. The differences for the parameters of group III have the same reason as the differences for the parameters of group I.

This example shows that the parameters correlate with properties of the mudflat surface. The conclusions done before are confirmed by investigations on the ground.

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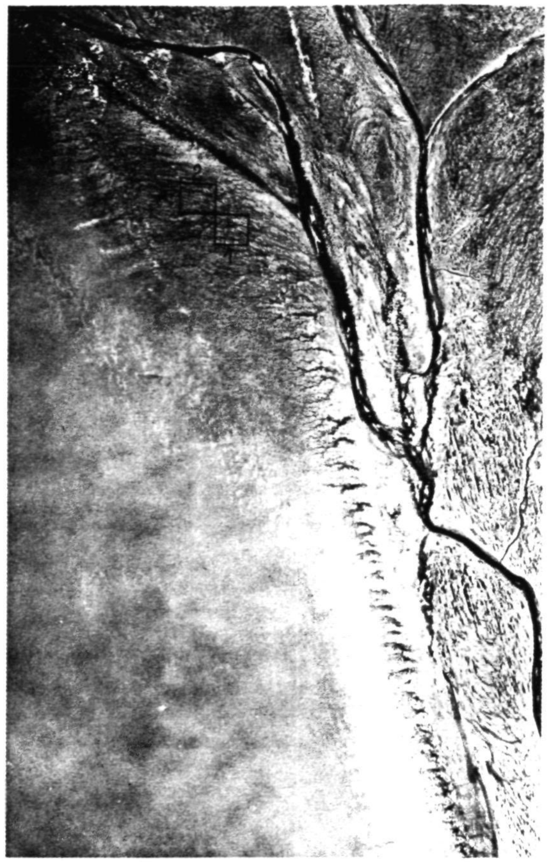

Fig.1: A section of the mudflat area in the North of Wilhelmshaven near Crildumersiel, scale 1:8000.