A NEW SEGMENT SHAPE PARAMETER FOR GRID DATA AND ITS APPLICATION TO LAND USE SEGMENTATION.

Manfred H. GÜNZL*, Olaf HELLWICH**
* Institute for Biomathematics and Biometrics
GSF-National Research Center for Environment and Health
Manfred@Guenzl.de
** Chair for Photogrammetry and Remote Sensing
Technical University of Munich
Olaf.Hellwich@photo.verm.tu-muenchen.de

KEY WORDS: Shape Parameter, Segmentation, Land Use, Algorithms, Mathematical Models, Radar

ABSTRACT

Various land applications require an image or image series to be divided into segments corresponding to areas of homogeneous land use. Image segmentation is needed to generate and update such GIS-stored geometric land use information. Regarding agricultural land use the shape of segments is a major feature to determine the correctness of a segment.
Most remote sensing data is derived and stored as grid data. Due to the fact that most region segmentation approaches are operating on such grid data, segments are handled as groups of grid cells. The shape of such segments is given by a polygon within that grid. The topic of this paper is a new approach to parameterize the shape of segments of grid data. A common approach to parameterize the shape is the compactness determined as the ratio of the area and the square of the boarder length. For polygons within a grid this parameter is highly dependent on the orientation of the segment. Regarding the application to remote sensing data, the major drawback of the parameter is that it depends on the sensor position and orientation. Due to the stairway-like shape some parts of the boundary usually are longer than the real boarder they approximate. In existing approaches, this effect is reduced by previously generalizing the polygon. This has two drawbacks. First of all the result depends on the way the generalization is conducted. The generalization of polygons enhances the compactness of the enclosed segment by simplifying its shape. To stay as close as possible to the shape of the original object, it is necessary to pay attention to the way the shape was effected by the image grid. Thereby the second drawback can be recognized: The generalization approach is computationally expensive.
In this work, a different, new approach is suggested. The goal was to determine the compactness of an object out of grid data by compensation of the influence of the image grid. The compensation was found to be possible using a set of geometrical parameters. This concept lead to a shape parameter with several advantages:

- The parameter is completely independent of the orientation of an object regarding the grid.
- The geometrical parameters of a segment derived out of merged segments can be determined from the parameters of the original segments. Thus, applied to region growing by merging, the computational effort is independent of the shape, size and girth of the regions and therefore constant. This enables shape-controlled region growing with the same order of computational effort as without shape control.
- The same set of parameters also enables the compensation of the lateral ratio of rectangular objects. This can be carried out independent of the orientation compensation.

Summarizing, the parameter describes the deviation of the shape of a segment from a rectangle. It derives to 1.0 whenever the segment is rectangular – independent of the location and orientation of the segment with respect to the grid, as well as of the ratio of side lengths of the rectangle. When the segment increasingly deviates from rectangular shape, the parameter increases continuously. As a result this new, computationally efficient shape parameter is perfectly suited to segment areas of agricultural land use usually consisting of rectangles.
The shape parameter was implemented as part of a computationally highly efficient region growing algorithm. Shape as a parameter for segmentation control is of special interest when applied to noisy data. Therefore, results of the segmentation of speckle influenced, simulated and real SAR data are given.

1 INTRODUCTION

Segmentation of remote sensed data of agricultural areas is the attempt to recognize homogeneously used regions. If someone evaluates such data manually and she or he is in doubt about the geometry of a field, she/he will usually make some assumptions:

- For technical reasons agricultural fields in most cases have got a preferably rectangular shape.
- Field boundaries are closed paths.
- Fields usually do not enclose other fields.

Using these assumptions the human viewer is able to ”interpolate” broken boundaries caused by disturbing influences like noise or speckle. Therefore, the consideration of the shape during an automatic approach of images segmentation is important to implement fault tolerance.

2 SHAPES WITHIN GRID DATA

Segments in grid data are usually represented by sets of grid cells. If such segments are topologically simple, their shape can be completely described by a single closed polygon. In case of grid data such polygons are chains of single grid cell boarders. In an orthogonal isotropic grid these chain links are vertical or horizontal boarders of two neighboring cells. Let $P \in \mathbb{N}$ be the number of enclosed grid cells (**p**ixels) and $E \in \mathbb{N}$ the number of single boarders (**e**dges) that form the surrounding polygon. Within a unit grid of 1×1 square cells, P is equal to the size of the enclosed area and E is equal to the length of the surrounding polygon. A common approach to parameterize the shape is the measurement of compactness according to $\frac{P}{E^2}$. In the general case this parameter is equal to $\frac{1}{4\pi}$ for a circle and smaller for all other shapes. In the case of a grid the maximum of $\frac{1}{16}$ is given by a square, if the boarders are parallel to the grid. Changing the squares orientation towards the grid causes a sampling error known as *aliasing* (Foley et al., 1997, 19.3.1). As a result E is greater than the true length of the squares boarder. The length of the real boarder of a $45°$ tilted square is factor $\sqrt{2}$ times shorter than the stairway like polygon. Therefore the aliasing causes an error in the measurement of compactness of up to factor 2.

2.1 Grid shape parameter

It is necessary to include the effects of grid sampling into the shape parameter to compensate this error. Let $C \in \mathbb{N}$ be the number of changes in the direction of the polygon (**c**orners).

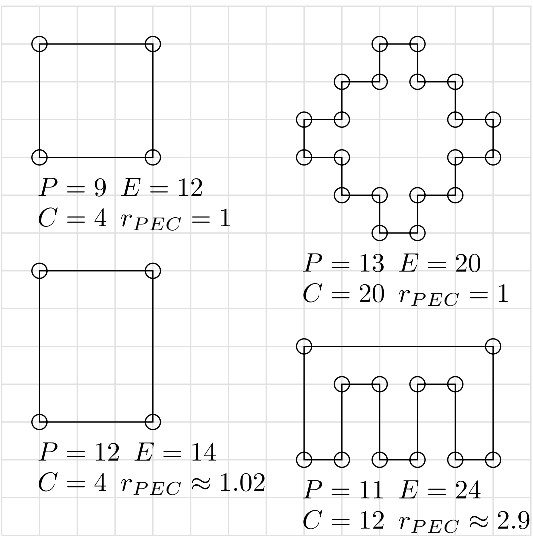

Figure 1: Some examples for the shape parameter r_{PEC}.

A slant towards the grid obviously increases C. Considering two squares one with parallel $\square$ and one with $45°$ slanted edges $\diamond$ we get the relations $E_\square^2 = 16 \cdot P_\square$, $C_\square = 4$, $E_\diamond^2 = 32 \cdot P_\diamond - 16$ and $C_\diamond = E_\diamond$. Out of these one can derive the general relation,

$$r_{PEC}(P, E, C) := \frac{2E^2 + 16 - C^2}{32P} \tag{1}$$

with $r_{PEC}(P_\square, E_\square, C_\square) = rpec(P_\diamond, E_\diamond, C_\diamond) = 1$ for all $0°$ and $45°$ slanted squares within a grid. The parameter r_{PEC} reaches its minimum of 1 for all squares with parallel or $45°$ diagonal edges. For all other less compact shapes r_{PEC} derives to values greater than 1. Some examples are given in figure 1.

Within r_{PEC} the parameter C is reducing the influence of the orientation by taking the aliasing into consideration. A polygon starting at point (x_1, y_1) approximating a straight line to point (x_2, y_2) within a grid contains $\Delta x := |x_1 - x_2|$ horizontal and $\Delta y := |y_1 - y_2|$ vertical lines. The length of the polygon is $\Delta x + \Delta y$ whereas the real length of the approximated straight line derives to $l = \sqrt{(\Delta x)^2 + (\Delta y)^2}$. Regarding the case $\Delta y > \Delta x$ the number of corners within the polygon is $2\Delta x$. The angle of the line towards the grid derives to $\omega = \arctan(\frac{\Delta x}{\Delta y})$. Every square consists of 4 parallel or perpendicular boarders that can be described in that way by their approximating polygon (→ figure 2). The parameters of such a slanted square results in

$$P_1 = 4\lfloor \frac{\Delta y \cdot \Delta x}{2} \rfloor + (\Delta y - \Delta x)^2, \qquad P_2 = 4\lceil \frac{\Delta y \cdot \Delta x}{2} \rceil + (\Delta y - \Delta x)^2, \tag{2}$$

$$\tilde{P} = 4\frac{\Delta y \cdot \Delta x}{2} + (\Delta y - \Delta x)^2 \qquad = (\Delta y)^2 + (\Delta x)^2 \quad \text{for} \quad P_1 \le \tilde{P} \le P_2, \tag{3}$$

$$E = 4(\Delta x + \Delta y), \qquad C = 8\Delta x + 4. \tag{4}$$

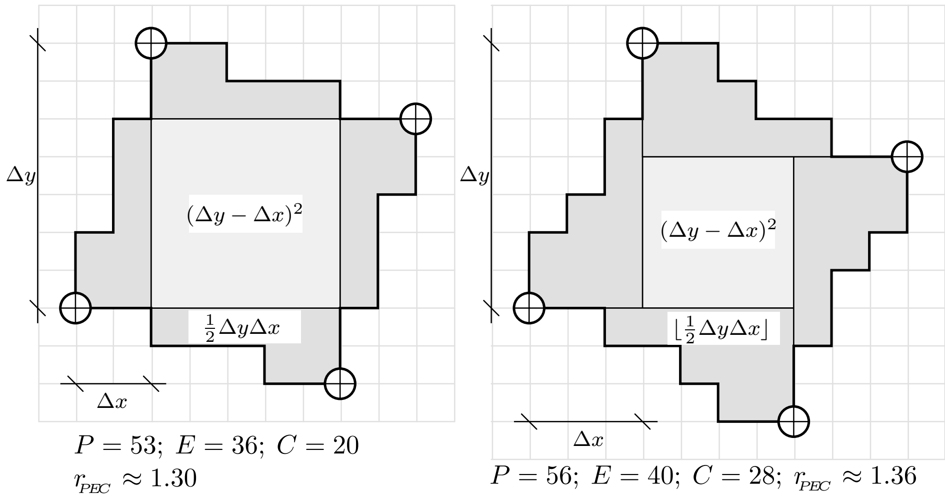

Figure 2: Squares approximated by grid cells with different slopes.

If the number of grid cells within the rectangle $\Delta x \times \Delta y$ can not be divided by 2, the approximating polygon can not divide it into two equal areas. Therefore, the distinction of the two cases P_1 and P_2 is required. The parameter r_{PEC} of a $l \times l$ square with the orientation ω derives to

$$r_{PEC}(\omega, l) \quad \approx \quad \frac{2E^2 + 16 - C^2}{32\tilde{P}} = \sin(2\omega) + \cos(2\omega) - \frac{1}{l}\sin(\omega), \tag{5}$$

This result can be used to compare the measurement of compactness derived by $\frac{P}{E^2}$ with the parameter r_{PEC}. The maximum error of factor 2 could be reduced to $\sqrt{2}$. The mean error of r_{PEC} derives to

$$\mathrm{E}(\underline{r_{PEC}(\omega, \infty)}) = \left(\int_0^{45^\circ} r_{PEC}(\omega, \infty) \delta\omega \right) / 45^\circ = \frac{4}{\pi} \approx 1.27. \tag{6}$$

2.2 Rectangular Shapes

For land use segmentation the square shape is not a common shape. To make working in the fields with machines easier most agricultural fields in central Europe have got a more or less rectangular shape with miscellaneous aspect ratios. If the boarders of a $l_a \times l_b$ rectangle are parallel to the grid r_{PEC} follows from $(P, E, C) = (l_a l_b, 2(l_a + l_b), 4)$.

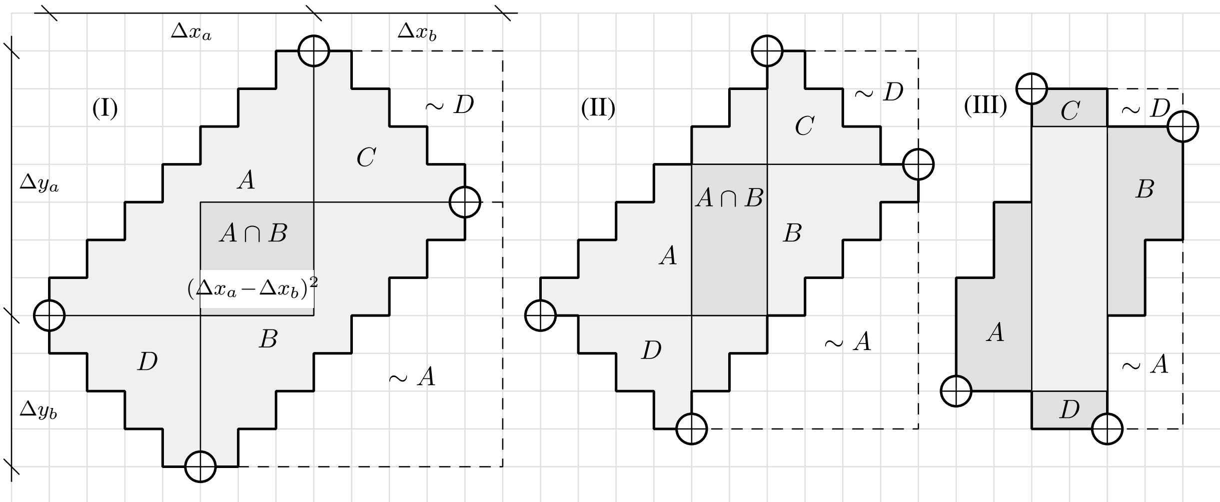

Figure 3: Rectangles approximated by grid cells.

$$r_{PEC} = \frac{(l_a + l_b)^2}{4 l_a l_b} = \frac{(v+1)^2}{4v} \qquad \text{for} \qquad v := \frac{l_a}{l_b} \tag{7}$$

This indicates that r_{PEC} is independent of the size and only depends on the aspect ratio. Analogous to the square one can assemble a rectangle out of 4 parallel or perpendicular boarders approximated within the grid (→ figure 3). Distinguishing the two cases (I) $\Delta x_a = \Delta y_a$, $\Delta x_b = \Delta y_b$ (I) and $\Delta x_a + 1 = \Delta y_a$, $\Delta x_b + 1 = \Delta y_b$ (II) r_{PEC} derives to

$$\text{(I)} \qquad r_{PEC} = \frac{(v+1)^2}{4v} - \frac{(v+1)(v-1)^2}{4v((\Delta x_b + \Delta y_b)v + v + 1)}, \tag{8}$$

$$\text{(II)} \qquad r_{PEC} = \frac{(v+1)^2}{4v} - \frac{(v-1)^2}{4v((\Delta x_b + \Delta y_b)^2 v + 1)}. \tag{9}$$

Both cases converge to the result of the parallel case as show in equation 7 for large rectangles. For twisted rectangles with an orientation of ω and $\Delta y_a > \Delta x_a + 1$, $\Delta y_b > \Delta x_b + 1$ the general case can be derived as

$$\Delta y_a \Delta y_b = \Delta x_a \Delta x_b = \Delta x_a \Delta y_b \tan(\omega), \tag{10}$$

$$(\Delta x_a, \Delta y_a) = l_a(\sin(\omega), \cos(\omega)), \tag{11}$$

$$(\Delta x_b, \Delta y_b) = l_b(\cos(\omega), \sin(\omega)), \tag{12}$$

$$r_{PEC} = \frac{(v+1)^2}{4v}(\sin(2\omega) + cos(2\omega)) - \frac{v+1}{vl_b}\sin(\omega), \tag{13}$$

$$r_{PEC} = \underbrace{\frac{(v+1)^2}{4v}}_{r_{PEC}(v)} \cdot \underbrace{(\sin(2\omega) + cos(2\omega))}_{r_{PEC}(\omega)} \qquad \text{for} \qquad l_b \to \infty. \tag{14}$$

As a result the influence of the aspect ratio v and the orientation ω can be splited into two independent factors $r_{PEC}(v)$ and $r_{PEC}(\omega)$. The fact that this is only possible for large enough rectangles with l_a and $l_b \gg 1$ is the mathematical analogy to the fact that objects with a size of the scale of the sampling cannot be recognized very well.

2.3 Error compensation

Equation 14 enables the compensation of the influence of the aspect ratio v and the orientation ω independently by multiplication of r_{PEC} with the reciprocal of $r_{PEC}(v)$ or $r_{PEC}(\omega)$. Applied to land use segmentation there is no *a priori* knowledge about these parameters.

A major advantage of r_{PEC} is that P, E and C can be derived with very little computational effort. Applied to region growing by merging (Schachter et al., 1979, Tilton and Cox, 1983, Beaulieu and Goldberg, 1989) it is possible to derive the parameters of a merged region out of the parameters of the initial regions with a computational effort that is independent of size and shape of the regions. This is possible, because P, E and C are all numbers of objects that can easily be added. In the case of a region merging the sum of E and C only need a correction with regard to the border that was removed.

To keep this advantage the goal of error compensation is to derive v or ω out of simple object counts. This can be realized using totals of enclosed grid cell coordinates. Let (x_k, y_k) be the coordinate of the enclosed grid cells with $1 \leq k \leq P$. Further let $\vec{x} := \{x_k\}$, $\vec{y} := \{y_k\}$, $\Sigma\vec{x} := \sum_{k=1}^{n} x_k$ and $\Sigma\vec{y} := \sum_{k=1}^{n} y_k$. Considering x_k and y_k as realizations of random variables $\underline{x}$ and $\underline{y}$ the variance and covariance are defined as

$$V_x := \mathrm{V}(\underline{x}) = \frac{|\vec{x}|^2}{n} - \left(\frac{\Sigma\vec{x}}{n}\right)^2, \qquad V_y := \mathrm{V}(\underline{y}) = \frac{|\vec{y}|^2}{n} - \left(\frac{\Sigma\vec{y}}{n}\right)^2, \tag{15}$$

$$\Delta V := V_x - V_y \quad \text{und} \quad C_{xy} := \mathrm{Cov}(\underline{x}, \underline{y}) = \frac{\vec{x}^T\vec{y}}{n} - \frac{(\Sigma\vec{x})(\Sigma\vec{y})}{n^2}. \tag{16}$$

The main direction of a set of point (x_k, y_k) is equal to the eigenvector $\vec{e}$ with the largest eigenvalue ε.

$$\begin{pmatrix} \mathrm{V}(\underline{x}) & \mathrm{Cov}(\underline{x}, \underline{y}) \\ \mathrm{Cov}(\underline{x}, \underline{y}) & \mathrm{V}(\underline{y}) \end{pmatrix} \vec{e} \stackrel{!}{=} \varepsilon\vec{e} \qquad \text{mit} \qquad \varepsilon \in \mathbb{R}, \vec{e} \in \mathbb{R}^2 \tag{17}$$

As both eigenvectors are orthogonal and the error of orientation $r_{PEC}(\omega)$ is $45°$ cyclic, it is insignificant whichever is used.

$$\vec{e}_{1/2} = \begin{pmatrix} e_{1/2,x} \\ e_{1/2,y} \end{pmatrix} = \begin{pmatrix} \Delta V \pm \sqrt{(\Delta V)^2 + 4C_{xy}^2} \\ 2C_{xy} \end{pmatrix}, \tag{18}$$

$$\omega = \arctan(e_{1,y}/e_{1,x}) = \arctan(-e_{2,x}/e_{2,y}), \tag{19}$$

$$r_{PEC}(\omega) = \sin(2\omega) + cos(2\omega) = \frac{|\Delta V| + 2|C_{xy}|}{\sqrt{(\Delta V)^2 + 4C_{xy}^2}}. \tag{20}$$

Using the former equation it is possible to derive $r_{PEC}(\omega)$ out of sums and squaresums of the coordinates of the enclosed grid cells. With this it is possible to define the orientation compensated shape parameter

$$\boxed{r_{PEC\omega} := \frac{2E^2 + 16 - C^2}{32P} \cdot \frac{\sqrt{(\Delta V)^2 + 4C_{xy}^2}}{|\Delta V| + 2|C_{xy}|}}. \tag{21}$$

In addition it is also possible to compensate the influence of the aspect ratio by using its relation to the ratio of the eigenvalues ε_1 and ε_2.

3 APPLICATION

Applied to land use segmentation this shape parameter can be used to evaluate the plausibility of the shape of a segment. Especially when applied to region growing by merging the parameter enables the computationally highly efficient distinction between plausible and implausible merging opportunities (→ figure 4). Using r_{PEC} or $r_{PEC\omega}$, segmentation algorithms

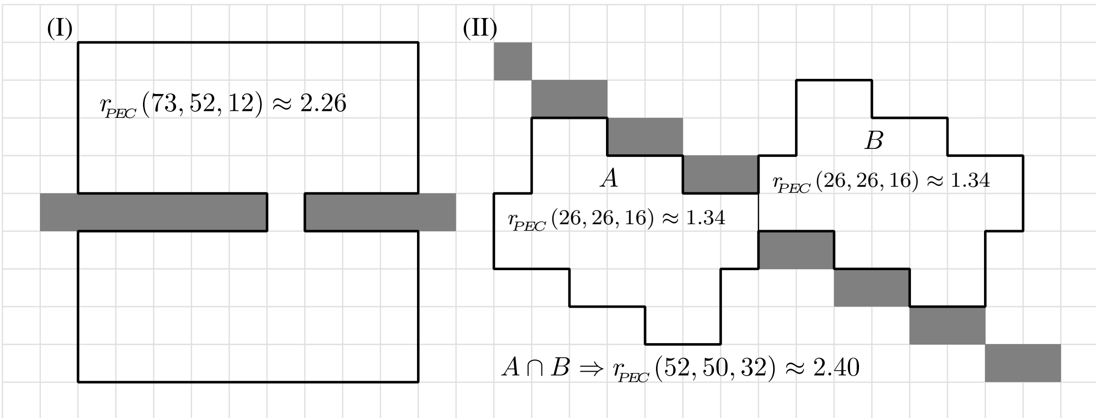

Figure 4: Two examples of implausible merging opportunities caused by imaging interference.

can be enabled to prefer rectangular shapes, and therefore, this is a mathematical tool to implement one facet of the human ability to assess land use shapes in remote sensed data. To demonstrate the "tidy" effect of the shape parameter the well known image of *Lena Soderberg* was segmented by recursive fusion of images pixels (→ image 5(a)). In all cases the 256×256 pixel image was reduced to 1000 segments. In example (b) the fusion criterion was to minimize the variance. In a greedy approach, from all possible fusions the one creating a region with the smallest variance was taken. In (c) the variance was multiplied by $r_{PEC\omega}$. The fusion creating the region with the smallest product of $r_{PEC\omega}$ and the resulting variance was taken. The influence of $r_{PEC\omega}$ divides narrow elongated objects into several segments. This effect can be reduced by an additional compensation of the aspect ratio as shown in example (d). Further details will be published in the authors PhD thesis.

Initially, this method was developed to enhance an ERS-SAR land use segmentation approach. Even manually, field boundary detection in ERS-SAR images was found to be very difficult. Using ERS C-band-VV data the only chance to delimit areas of different crop types or other slightly different kinds of land use, is to analyze time series during the vegetation period. A series of seven ERS-SAR-SLC scenes with a 35 day period from March till October was registrated to each other. The histogram-equalized signal intensity of the May data for a test side near Munich is shown in image 6(a). Ground truth data was determined by GPS measurements. To get an absolute measurement of segmentation quality, an idealized dataset was build by filling GIS polygons of land use segments with their mean signal intensity (→ image 6(b)). After application of SAR speckle (→ image 6(c)), these scenes were segmented and compared to the GIS data. To derive a measurement of quality for the segmentation, the GIS regions were checked whether they were completely and exclusively covered by a segment. If a segment covers more than 50% of a GIS-region and the region covers more than 50% of the segment these two were taken as complementary. Let $\mathcal{P}_i$ be the set of grid cells within the ith GIS region and $\mathcal{S}_i$ the set of cells within the complementary segment. If there is no complementary segment, let $\mathcal{S}_i = \emptyset$. The error of incompleteness e_1 is given by

$$e_1 := 1 - \frac{\sum_i \mathrm{card}(\mathcal{P}_i \cap \mathcal{S}_i)}{\sum_i \mathrm{card}(\mathcal{P}_i)}.$$

Figure 5: The well known image of Lena Soderberg (a) reduced to 1000 segments minimizing the variance (b), multiplied with $r_{PEC\omega}$ (c) and multiplied with a aspect ratio compensation (d).

whereas the error of non exclusive coverage is given by

$$e_2 := 1 - \frac{\sum_i \operatorname{card}(\mathcal{P}_i \cap \mathcal{S}_i)}{\sum_i \operatorname{card}(\mathcal{S}_i)}.$$

Where $\operatorname{card}(\mathcal{S})$ is the number of members of the set $\mathcal{S}$. As a total measurement of quality the sum $e := e_1 + e_2$ of these two kinds of errors were taken. The application of extracted speckle on idealized data enables the analysis of data with a different signal to speckle ratio. In case of SAR data, n-look images with uniform resolution can be simulated using data from one single flyover.

A region growing by merging algorithm keeping track of the parameters needed to derive $r_{PEC\omega}$ was implemented. Starting with every single pixel as a region with four neighboring regions, a recursive merging is applied. Storing neighborhood relations along with the geometric parameters P, E, C and the pixel coordinate sums and square sums within a binary heap data structure (Cormen et al., 1990, 7.1) enables a computationally efficient continuous update of $r_{PEC\omega}$ during the segmentation process. Using this heap data structure the computational effort for a segmentation of a $p \times q$ image matrix is of the order $O(pq\,\mathrm{ld}(pq))$. The canonic region growing approach without the shape parameter is shown in figure 6(d) with $e = 0.88$. The merging criterion was to minimize the standard coefficient of variation (SCV) (Beaulieu and Goldberg, 1989, Tilton and Cox, 1983, Tilton and Ramapriyan, 1988). The SCV was taken instead of the variance because of multiplicative character of the speckle effect. Applying the shape parameter just by multiplying the SCV and $r_{PEC\omega}$ similar to the Lena image example leads to very bad results with $e = 0.96$ as shown in image 6(e). Never the less extensive tests with different combination operators and weighting parameter showed that even in this case the shape parameter is able to improve the segmentation quality slightly. As an example using $SCV \cdot \mu_A(r_{PEC\omega}, P)/l^{\frac{1}{66}}$ gives a result of $e = 0.73$ shown in image 6(f). Where l is the length of the boarder to remove and μ_A is Zadehs S-Function used to control the influence of $r_{PEC\omega}$ dependent on the segment size P.

4 CONCLUSIONS

The application of the shape parameter r_{PEC} in a region growing algorithm pinpointed two mayor problems.

- The decision of a further fusion step needs to be derived out of a combination of radiometric and geometric parameters. Even if both of them are sources of evidence they can disturb each other if combined to a merging criterion. Applied on single look SAR date with a signal to noise ratio of one in most cases the application of a shape parameter leads to worse results as shown in image 6(e). In the early stage of the segmentation the correlated speckles with there compact shapes are increased. Using more complicated operators and weighting parameters to combine radiometric and geometric parameters can solve this problem. The drawback that prevents the practical application is that right now there is no way to derive these parameters from *a priori* knowledge. The better the signal to noise ratio the less critical the combination of radiometric and geometric parameter is.
- The second principal problem is the application of r_{PEC} in greedy algorithms. Trying to keep segments as rectangular as possible during the entire segmentation process sometimes prevents the algorithm from finding large rectangular objects that need to be assembled out of non compact shapes. Comparisons with simulations of uncorrelated speckle showed that this is particularly valid when applied to data with correlated speckle.

ACKNOWLEDGMENTS

These investigations are a part of the EMAP project. EMAP is equally financed by the German Aerospace Center (DLR) and the German Federal Ministry of Agriculture (BML). The test site is located in southern Bavaria between Munich and the Danube river. Three sequences of 7-8 ERS-2-SAR-SLC images per year, acquired between March and October, have been kindly provided by the European Space Agency (ESA).

REFERENCES

Beaulieu, J.-M. and Goldberg, M., 1989. Hierarchy in picture segmentation: a stepwise optimization approach. IEEE Transactions on Pattern Analysis and Machine Intelligence 11(2), pp. 150–163.

Cormen, H. T., Leiserson, C. E. and Rivest, R. L., 1990. Introduction to Algorithms. McGraw-Hill.

Foley, J. D., van Dam, A., Feiner, S. K. and Hughes, J. F., 1997. Computer Graphics — Principles and Practice. 2 edn, Addison-Wesley Publishing. ISBN: 0-201-84840-6.

Schachter, B., Davis, L. and Rosenfeld, A., 1979. Some experiments in image segmentation by clusterin of local feature values. Pattern Recognition 11(1), pp. 19–28.

Tilton, J. and Cox, S., 1983. Segmentation of remotely sensed data using parallel region growing. In: Digest of the 1983 International Geoscience and Remote Sensing Symposium — San Francisco, CA, pp. 9.1–9.6.

Tilton, J. and Ramapriyan, H., 1988. Data compression experiments with landsat thematic mapper and nimbus-7 coastal zone color scanner data. In: Proceedings of the Scientific Data Compression Workshop — Snowbird, UT.

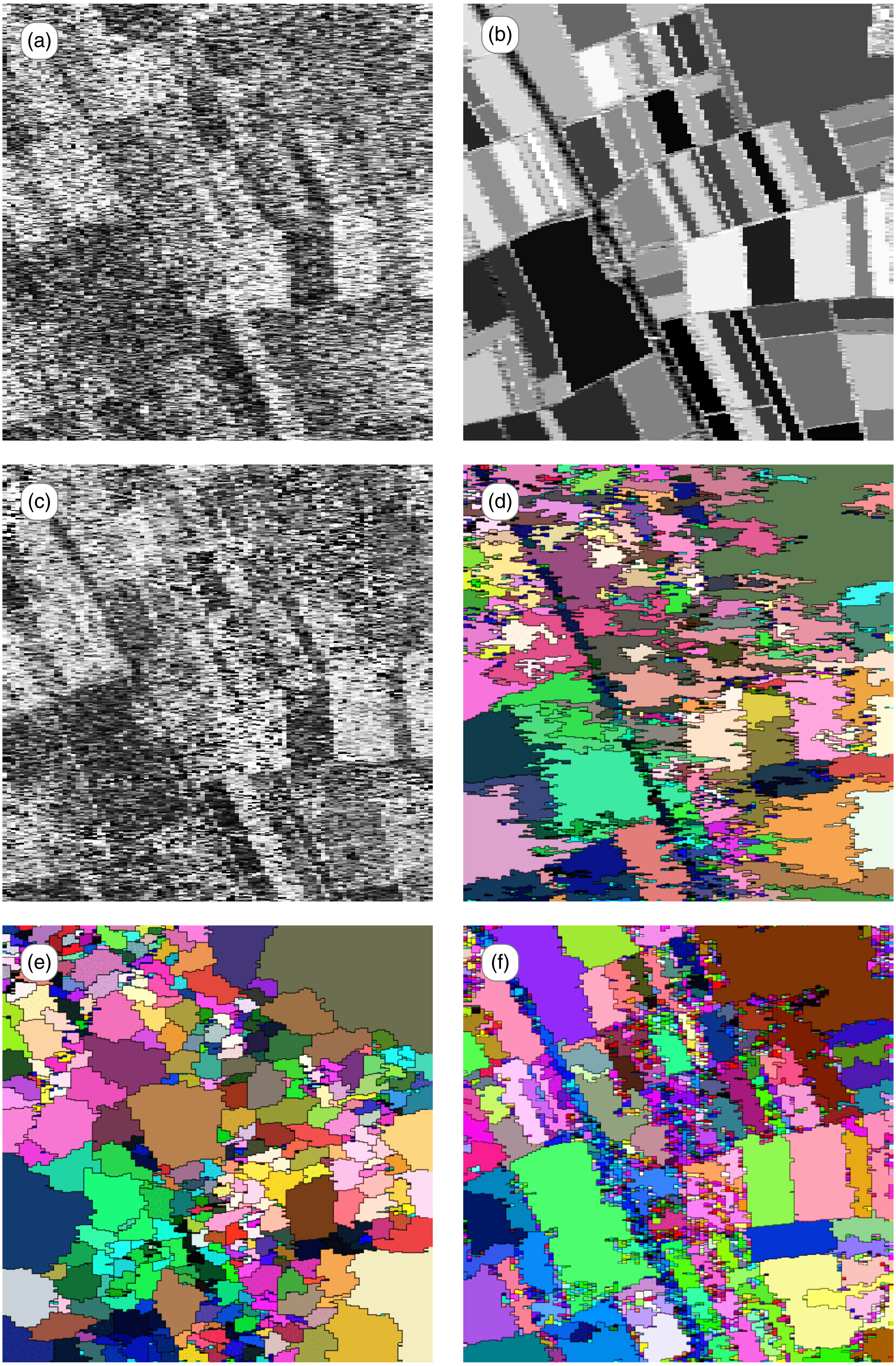

Figure 6: Examples of the experimental data.