

AUTOMATIC DERIVATION OF GENERALIZED CONTOUR LINES FOR TOPOGRAPHIC MAPS USING HIGH-RESOLUTION AIRBORNE INTERFEROMETRIC RADAR DATA

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ABSTRACT

Derivation of contour lines from a Digital Elevation Model (DEM) has to cope with a number of problems. (1) bad approximation of angular lines, (2) none or badly placed line inscriptions, (3) discontinuity when combining contour line sets of adjacent map sheets. We present a software system capable of dealing with the mentioned problems. A Raster-DEM derived from interferometric synthetic aperture radar (InSAR) AeS-1 data, operated by AeroSensing Radarsysteme GmbH, serves as input for the software system. Prior to vector processing of the contour lines, DEM smoothing and local peak detection are performed on the raster data. Contour lines are organized in point and polygon lists. Various algorithms operate on the polygon/point list data structure, e.g. breaking of contours touching the map border, removal of small contours by thresholding on the number of tie points. The core of the program is the generalization module performing line smoothing and generalization. Three different approaches have been implemented: take each Nth point, Pavlidis and the Douglas-Peucker algorithm. The latter performed best with respect to contour line quality / time consumption tradeoff. To ensure continuity between map sheets, an overlap area forming a skirt on all four borders is constructed and contour lines are cutted in appropriate fashion. Another important capability is automatic generation of line inscription. Graphic attributes for lines and inscriptions, especially font size, line type and thickness, inscription insertion point and angle are derived from the map scale requirements and local line properties. The resulting DXF-file consists of three layers: the main contour lines, the intermediate contour lines and the text, i.e. the line inscription. Further use of resulting DXF-data in a GIS system, in our case ARCView, is possible.

1 INTRODUCTION

Contour lines are the main graphical element to characterize 3-dimensional terrain on 2-dimensional map sheets. In this paper, an automatic way to derive terrain characterization employing contour lines is investigated. Automation of contour line extraction completes automated geocoding, georeferencing, classification and object detection from the remote sensing product. Contour line extraction from a DEM usually results in a large number of contours. Each contour is described by a polygon, which in turn consists of a number of points connected by straight lines. Simplification of these polygons is aspired from two points of view: computational and cartographic. From the computational point of view, a smaller number of points, up to our experience a portion of 1/20, reduces storage and processing costs significantly. Concerning the second point of view, the cartographer attempts to maintain the character and overall impression of the contour, while selecting representative points and deleting the rest (Douglas and Peucker, 1973).

In this paper we will not try to suggest new contour extraction or simplification methods, we will rather address the fully automatic derivation of the DEM and the subsequent, also performed automatically, derivation of topographic map sheets containing simplified contour lines and inscriptions. Embedding this system into a SAR/InSAR processing chain and combining it with automatic classification tools, a raw map product for further manual postprocessing in common GIS software, such as ARC View GIS, is provided. Results concerning time consumption, accuracy of contours when compared to ancillary data, and completed products are presented.

All presented results are based on data provided by the high-resolution airborne AeS-1 interferometric X-Band SAR system (Moreira, 1996).

2 GENERATION OF DIGITAL ELEVATION MODELS FROM INTERFEROMETRIC SAR

SAR is an active sensor, which means that it illuminates the imaged area by transmitting and receiving microwaves. Interferometric SAR (InSAR) employs two receiving antennas as shown in Figure 1 (b). Whereas in the conventional

SAR (see Figure 1 (a)) it is not possible to discriminate between points P_1 and P_2 due to the height difference H , in InSAR the height difference causes a difference in the range ΔR . This ΔR is measured as a phase difference between the signals received by antennas S_1 and S_2 . The separation between S_1 and S_2 is called the *baseline*.

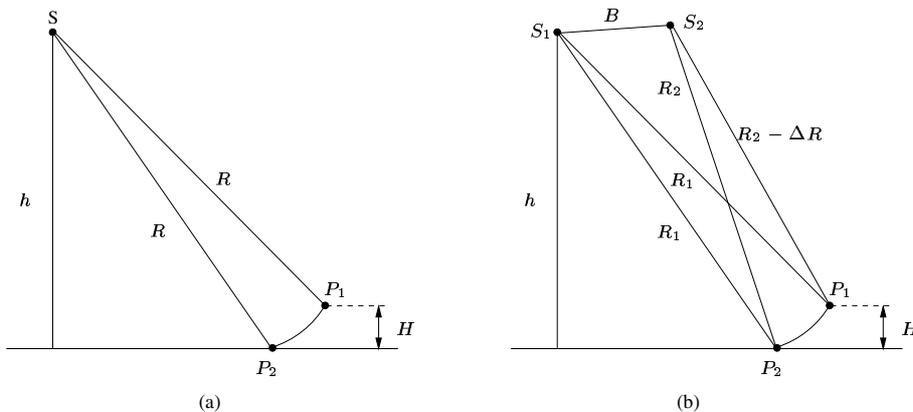


Figure 1: Distance Measurement using SAR: (a) Conventional SAR, (b) Interferometric SAR

The phase difference measurement $\Delta\phi$ is given by:

$$\Delta\phi = \frac{2\pi}{\lambda} \Delta R. \quad (1)$$

Geometrical considerations lead to a phase difference measurement for each pixel. Phase measurement is restricted to the $[0 \dots 2\pi)$ range, thus resulting in ambiguity. An *interferogram* visualizes those *fringes* in the phase. A range dependent phase component is removed from the interferogram through removal of the so called *flat earth phase*. The process of *phase unwrapping* is employed to resolve ambiguities caused by the $[0 \dots 2\pi)$ phase range. Unwrapped phase is related to terrain height by phase-to-height conversion. Figure 2 summarizes the necessary steps to derive a DEM from interferometric SAR processing.

The InSAR for DEM generation principle was for instance reported in (Graham, 1974), (Zebker and Goldstein, 1986) and (Schwäbisch, 1998). Successful application of the mentioned technology using the the AeS-1 instrument was described in (Moreira, 1996).

3 COUNTOUR LINE EXTRACTION AND APPROXIMATION

In contour line approximation or generalization three requirements can be defined: (1) The contour lines must be simple, which means the number of points is reduced, (2) the contours must appear smooth, and (3) the characteristic of the contour must be retained, e.g. parallel lines, specific shapes, etc, (Li et al., 1999).

Different measures of error between the approximation and the original contour points are possible. The two most prominent error measure are the maximum error E_{max} and the summed square error E_{sse} (Pavlidis, 1982):

$$E_{max} = \max_i |p'_i - p_i|, \quad E_{sse} = \sum_i (p'_i - p_i)^2, \quad (2)$$

where p'_i is the original tie point and p_i an approximated point (i.e. the closed point to p'_i on the approximation line).

The most simple algorithm for line simplification, the *takeM* procedure, does not take into account the stated requirements, as expressed by error measures. Despite from this, it is computationally most efficient. It proceeds as follows (where M is a small integer):

1. Let a polygon P be an ordered list of N points $p_i, i = 1, \dots, N$.
2. Construct a new polygon P' containing all p_i for which $(i - 1)/M$ is an integer.

The algorithm by Pavlidis uses the E_{max} criterion. It employs a split-and-merge technique based on approximative collinearity and angle criterias for groups of lines:

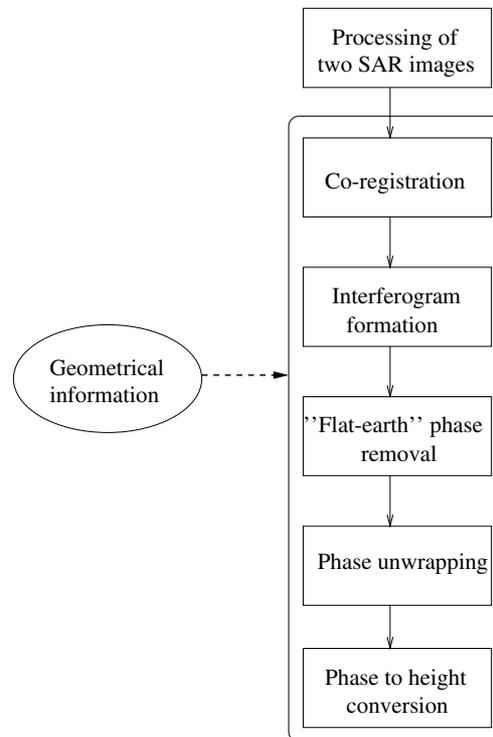


Figure 2: Derivation of a DEM from Interferometric SAR Measurements

1. Let a polygon P be an ordered list of N points $p_i, i = 1, \dots, N$.
2. Let k_0 be the number of points normally approximated by a single line. Let $L_1 = \overline{p_p p_j}$ be the line connecting points p and j .
3. Let $p = 0, j = 0, k = k_0$.
4. Test, if points j and k are approximate collinear. Let m be the point where E_{max} occurs.
5. If the collinearity test is true, then $L_2 = \overline{p_j p_k}$, else let $k = m$ and goto (4).
6. If $p = j$, then $L_1 = L_2$.
7. If $p \neq j$ and angle between L_1, L_2 is small, then $L_1 = \overline{p_p p_k}$.
8. If $p \neq j$ and angle between L_1, L_2 is large, then $p = j$ and $L_1 = L_2$.
9. Let $j = k$ and $k = k + k_0$.
10. If $j < N - 1$ then goto (4).

The Douglas–Peucker algorithm employs some predefined E_{max} value in approximation. A maximum distance criterion for sequentially shrinking groups of lines is applied:

1. Let a polygon P be an ordered list of N points $p_i, i = 1, \dots, N$.
2. Set index of anchor point a to $a = 1$ and index of floating point f to $f = N$.
3. Find point p_k , where k lies in the range a, \dots, f having maximum perpendicular distance d from a straight line $\overline{p_a p_f}$ connecting anchor and floating point.
4. if $d \geq E_{max}$ then let $f = k$.
5. if $d < E_{max}$ then $a = f$ and $f = N$.
6. if $a \neq f$ then goto (3).

The main evaluation point criteria for the three mentioned contour smoothing methods are the appearance of the line and its error with respect to existing map products. Both issues will be addressed in the last section. Height inscriptions can also be automatically derived, and the quality thereof can be evaluated by graphical attributes, which are: placement, readability and direction.

4 AUTOMATED SYSTEM

The tasks of the various modules depicted in Figure 3 are:

Extraction: The number of height levels is calculated from map scale requirements and InSAR DEM elevation range. To extract initial contour lines a line-following method is applied to the DEM.

Segmentation: Contour lines are either closed or open. Open contours touch the border, therefore previously closed contours touching the border have to be segmented into open contours.

Thresholding: Depending on the map scale, contours are drawn around objects of a given minimum extension. Thresholding eliminates contours describing objects which can be neglected.

Approximation: This is the contour smoothing step discussed in the previous section.

Labeling: The inscriptions are placed constrained to some placing and direction rule.

Approximate continuity between independently processed mapsheets is ensured through processing of a larger view, i.e. adding of a border, and cutting off this border after smoothing. Conversion of labeled contours to Drawing Exchange Format (DXF) is a straightforward final processing step.

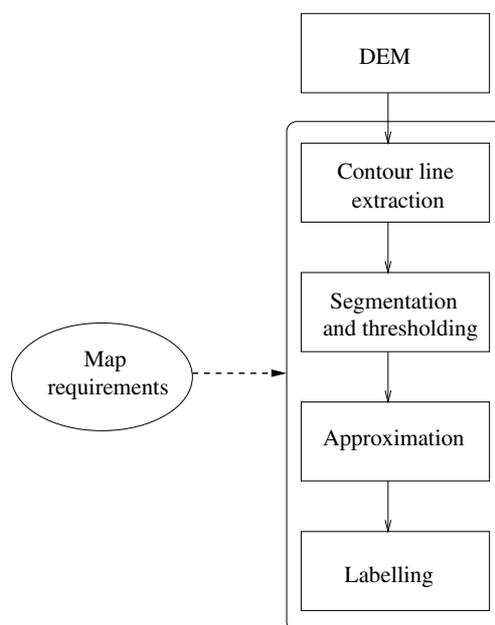


Figure 3: Contour derivation, approximation and labeling from DEM

5 RESULTS

5.1 Performance Measurements

Table 1 gives estimates for the completion of contour line processing, including file output in DXF format.

Image size	Number of polygons	Computation time
512 x 512	20	17 sec.
1024 x 1024	50	48 sec.
2113 x 2077	140	5 min. 35 sec.
3000 x 1450	21837	12 hrs. 21 min.
Used machine: Pentium II, 233 MHz, 256 MB RAM		
Used system: IDL 5.0 on Linux x86		

Table 1: Performance measurements of the contour line extraction, smoothing and output process

5.2 Quality of Contour Lines

Figure 4 shows the results for the different methods. A visual comparison of the derived contour lines with ancillary contour lines issued by the Bavarian topography survey office showed, that the accuracy is in the range of ± 1 meter. Due to the fact, that the latter contour lines come from a survey of the year 1911, we can assume that there was some topographic erosion since these times. So, the comparison of our data, recorded in 1997, with this old data is somehow problematic because of the 86 years time lag.

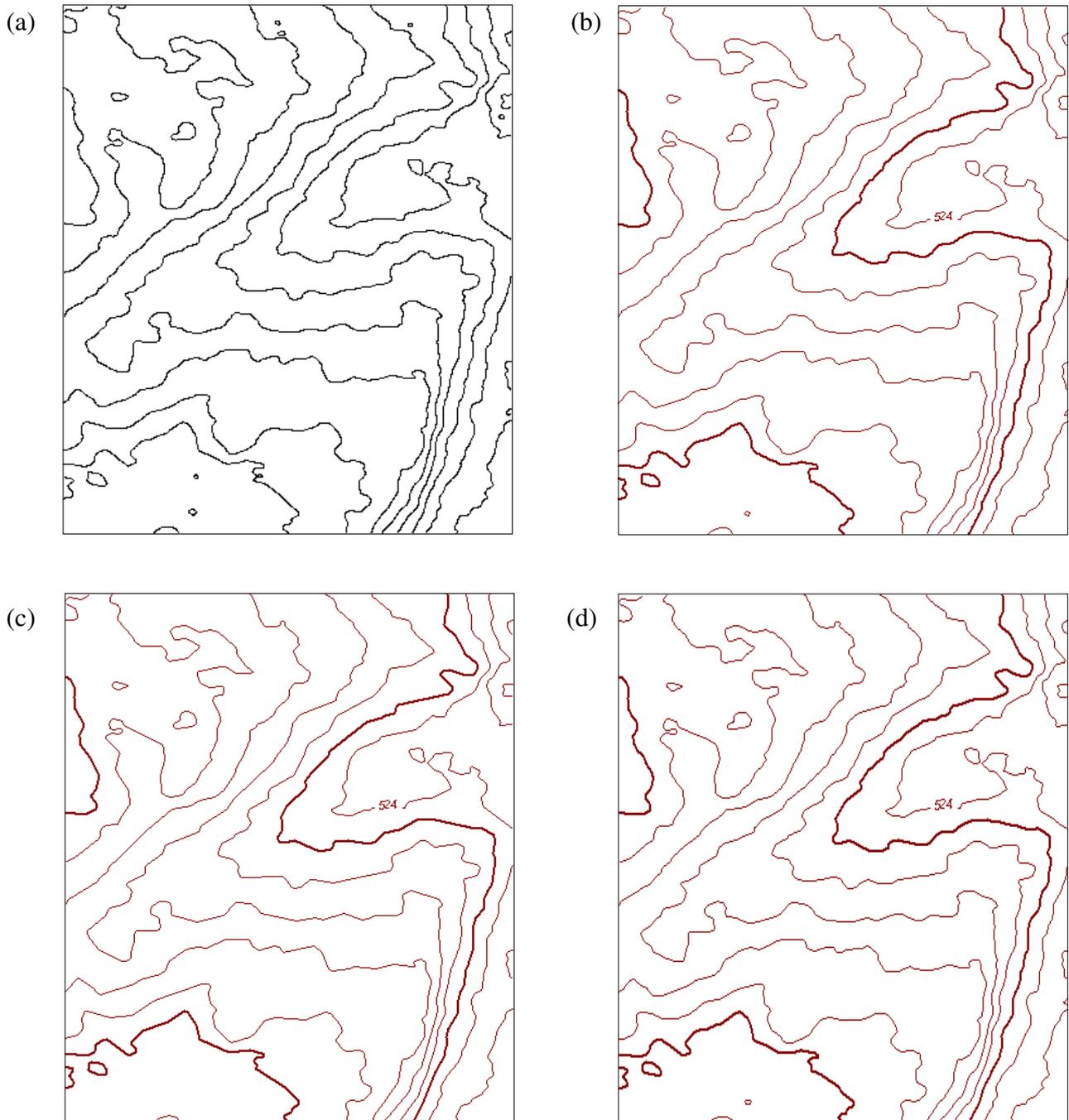


Figure 4: Countour Line Approximation Methods: (a) No approximation, (b) take each 10th point, (c) Pavlidis and (d) Douglas–Peuker.

5.3 Cartographic Products

Figure 5 the comparison to the ancillary data for the contour lines smoothed using the Douglas–Peuker algorithm, which was visually identified to produce the best results. Additionally, manual classification derived from X–Band radar backscat-

ter is shown in the map.



Figure 5: Map derived from InSAR data and ancillary map.

6 CONCLUSION

A system for automatic contour line extraction and labeling used in an operational context was described. Progress in automatic derivation of DEMs from InSAR data request the existence of subsystems as the described one. The system produces reasonable results for further use in GIS systems. Further improvements may concern some specific questions, such as the use of general curves instead of lines, avoidance of contour lines intersection, optimal inscription placement rules and placement of single topographic height points to mark local extrema.

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