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Final Supplemental Technical Report

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A software system to implement the automatic extraction of linear features from large area aerial images is described. Details of the input parameters, the structure of the input image data and the structure of the output data are given.

Contents

Preface

The Research reported in this document has been made possible through the support and sponsorship of the U.S. Government through its European Research Office. This report is intended only for the internal management use of the Grantee and the U.S. Government.

The work was performed in the period of August 1980 to April 1981.

1. Statement of the problem

The final technical report /1/ describes three methods for the cooperative extraction of line shaped objects from aerial photographs. The first method calculates starting points for the extraction. The two other methods are the local method and the regional method for line following. The three algorithms originally were implemented in Standard-FORTRAN on a minicomputer DEC PDP 11/70. Due to the limited working storage the three methods were implemented as three separate program systems.

All programs have been transfered to a VAX 11/780 computer and integrated into one system. The extraction runs completely automatically and large image data can be processed.

The following chapters describe the hardware configuration, the implemented software system and the process of the extraction in large image matrices. A complete printout of the computer program is added as a separate document. A magnetic tape with all source files is available from USAETL. (The programs were implemented for the purposes of a research project to test the methods for the extraction of linear features, they are neither optimized nor purged).

2. The FIM image processing system configuration, overview and block diagram of the implemented software system for the automatic extraction of linear features

Figure 1 shows the FIM image processing system configuration. Originally the automatic extraction of linear features was implemented on the PDP 11/70. During the extraction the results are displayed on a COMTAL color display with interactive control. So the interpreter can stop and correct the calculations if necessary. The image data is digitized with the DICOMED scanner where images up to 6 cm x 6 cm can be scanned with 512 x 512, 1024 x 1024 or 2048 x 2048 pixels.

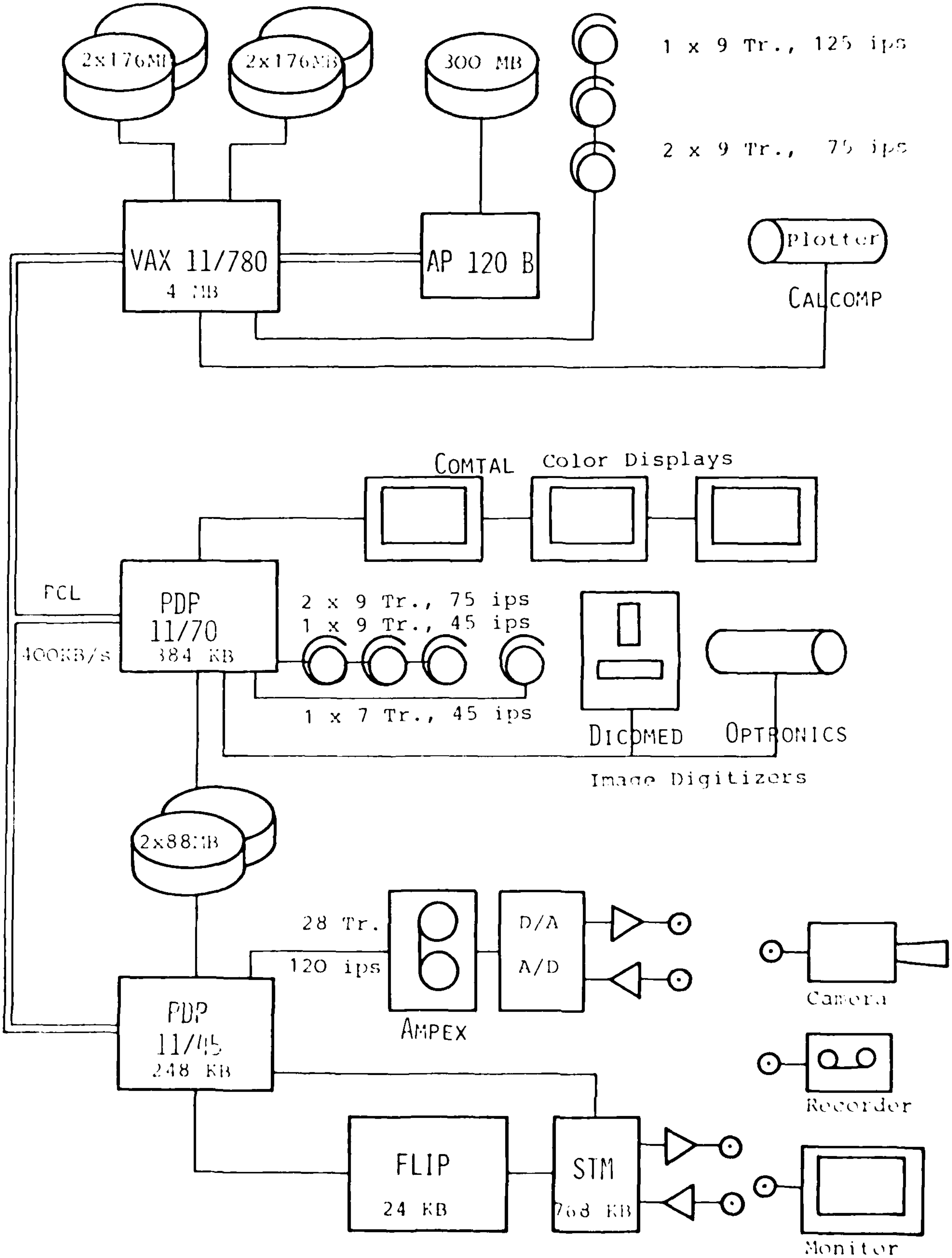


Figure 1: The FIM image processing system configuration.

Due to the limitations of the PDP 11/70 only small parts of the image matrices can be stored in the working storage which causes a lot of data transfer. For the same reason the starting point analysis and the local and the regional method for line following had been implemented as three separate program systems. Each system consists of a large amount of subroutines using overlay programming structures.

The cooperation of the three systems is simulated interactively. The first stage of the cooperation is the calculation of starting points. The search for starting points is limited to a grid of test lines which is spread over the whole image. Then the local method extracts all parts of the network of lines which are within reach of these starting points. The extraction is continued by the regional method at the dead ends. The regional method is followed by the local method etc.. If none of the methods yields further results the evaluation of the image is terminated.

The fact that during the extraction all intermediate results are displayed on a graphic overlay of a COMTAL color display is used to prevent the multiple extraction of lines. For every new line segment the data of the graphic overlay corresponding to the location of this line segment are checked whether it has already been detected or not.

To enable the cooperation between the three separate program systems the results are stored in two data files on disk storage. The starting point method writes the results on a scratch file from where the local method can read the starting points.
The local method and the regional method use the same data file appending new results to the results obtained earlier.

On the VAX 11/780 the three separate systems are integrated into one system without overlay programming structure. So the cooperation of the three parts is performed fully automatically. At first the starting point method evaluates the grid of testlines until the first starting point is detected. The control is switched automatically to the local method which extracts all possible parts of the network of lines. The regional method tries to continue the extraction at the dead ends until object properties acceptable for the local method are detected again. After evaluating all dead ends the control is switched back to the local method etc. If the regional method fails at all dead ends the next starting point is searched. For that the starting point method continues to evaluate the grid of testlines. The algorithm stops if no more starting points can be found on the grid.

By calculating only one starting point at a time, it is assured that no redundant starting points are detected in one connected part of the network of lines. The extraction process itself is performed automatically. The final results are stored in two data files, one with linked and one with cellular data organisation /2/. The linked data organisation consists of polygons and special header information; each polygon corresponds to a line object. The cellular data organisation consists of a byte matrix of the same size as the image matrix where the lines (and special attributes) are mapped one to one. During the extraction this matrix is checked to prevent the multiple extraction of a line. The final results can be printed on a lineprinter, plotted on the CALCOMP plotter or displayed on a COMTAL color display.

In contrast to the PDP 11/70 the VAX 11/780 allows processing of large image data. Aerial photographs up to 23 cm x 23 cm can be scanned with the OPTRONICS image digitizer with a resolution of 25 μm, 50 μm or 100 μm. The resulting image matrices are split into subimages of 512 x 512 pixels each which are adequate to the working set and can be stored at once in the working storage of the VAX. The extraction in a subimage is performed as described above. The locations where lines are bounded by the picture limits are stored as socalled Dead Ends at Picture Limits (DEPLs). These DEPLs are used to continue the extraction in neighbouring subimages. The following block diagram (figure 2) demonstrates the extraction process in large image data which are split into subimages.

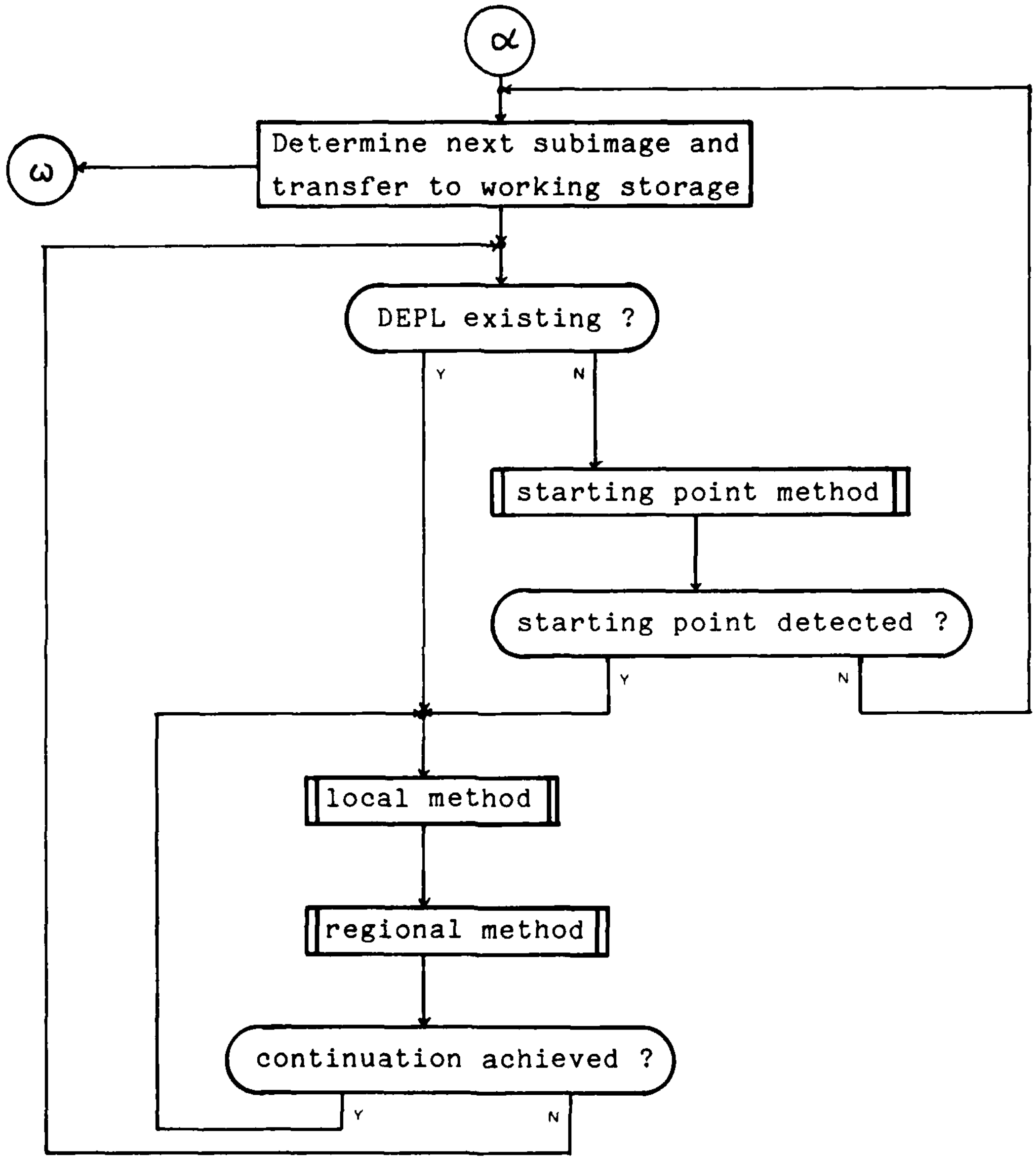


Figure 2: Block diagram for the extraction process in large image data.

3. Details of the software system

3.1 Input data and parameters

The input image data is a gray level matrix (scanner data or mostly digitized analogous aerial imagery). The width of the objects depends on the resolution of the scanning. As described in /1/ the special line detectors rely on a sophisticated analysis of gray level diagrams where they recognize and isolate the gray level profile of the objects cross section. The length of the profile, i.e. the width of the object, should exceed one pixel, because peaks of one pixel can simply be produced by noise. For practical reasons the upper limit for the object width is approximately ten pixels in the implementation.

Most line shaped objects in aerial imagery are either light or dark compared with their surrounding in the whole image. In panchromatic photographs roads mostly stand out light and rivers mostly are darker than their surrounding. In scanner data this is different, because the same object can be light in one spectral band and dark in another.

At the beginning of the extraction the interpreter enters the name of the image data file. The resolution of the scanning is coded in the image file header. All parameters automatically get standard default values which are suitable for the usual case, the extraction of light main roads. If this class of objects is to be extracted no further input is necessary. If other classes of objects are to be extracted, the interpreter has to specify the width of these objects and whether they are light or dark. All other parameter values are derived from these two values and the scanning resolution. Additionally special parameters for the extraction itself are obtained by analysing the surrounding of the starting points, once they are detected. Thus the object specific extraction of each particular class of objects is possible, e.g. small roads can be extracted while main roads, highways, rivers etc. are disregarded.

3.2 Structure of the input test data

The goal of this project was to extract linear features from parts of aerial images with a sidelength up to 20 cm and a scale of 1 : 74 000. To obtain at least two pixels even on small roads the images were scanned with the OPTRONICS scanner using a distance of 25 μm between neighbouring scanning points. This resolution yields data files of 8192 x 8192 pixels for every 20,5 cm x 20,5 cm image. To profit best of the computer memory working set the image matrix of 8192 x 8192 pixels was split into 17 x 17 overlapping submatrices of 512 x 512 pixels each. The overlapping range between neighbouring subimages is 32 pixels. This is necessary because the DEPLs consisting of a line segment have to be part of both subimages. Moreover in case of a smaller overlapping it might be necessary to change images very often to extract an object close to the picture limits.

3.3 Structure of the output data

The intermediate result of the extraction in a 512 x 512 subimage is a string of coordinates, where each pair of coordinates corresponds to a point on a line object. Mostly two successive points are not neighbouring points, their distance depends on the width of a step in the local method or the distance of the intersecting lines in an AoI of the regional method.

The final results are of two different kinds, known as cellular and linked data organisation. For the first final result the gaps between two successive points are interpolated. This yields connected chains of points along all extracted line objects. These points are stored in a 512 x 512 byte-matrix where each position corresponds to the same position in the relative 512 x 512 image submatrix. The eight bits per matrix element can be used to code

- if this position belongs to a line object,
- if the relative point in the image is a crossing between line objects, a dead end or a DEPL,
- the class of the object (e.g. road, highway),
- the width of the object,
- the kind of contrast (light object or dark object),
- if the point was a starting point
- and which method has performed the extraction.

This kind of data organisation suits well for printing the final results as contour map on a line printer or displaying them on a COMTAL color display.

In the linked data organisation the final results are stored in a reduced form. To do this a polygon approximation is performed for every line object, so that only the ends (dead ends, DEPLs or crossings) and the corners of the lines remain. The polygons are stored in list form as a string of coordinates where different polygons are separated by special coding. Additional information is stored in headers, or pointers in the headers indicate where the information can be found. This type of final result suits well for plotting the results on the CALCOMP plotter.

3.4 Size of the software system and program listings

The system for the extraction of linear features is implemented in Standard FORTRAN IV.

The three main blocks of the system are

a) the starting point analysis,
14 programs (FORTRAN routines),
approximately 2000 statements,

b) the local method,
36 programs (FORTRAN routines),
approximately 5000 statements,

c) the regional method,
37 programs (FORTRAN routines),
approximately 2500 statements.

The whole system consists of approximately 9000 statements in 89 programs (FORTRAN routines).

A complete printout of the computer program is added as a separate document. A magnetic tape with all source files is available from USAETL. (The programs were implemented for the purposes of a research project to test the methods for the extraction of linear features, they are neither optimized nor purged).

The first program is SUCOUT which manages the cooperation of the three subsystems. Behind SUCOUT and one subroutine called from SUCOUT the three subsystems follow separately where each subsystem is ordered alphabetically.

4. Possibilities to speed up the extraction of linear features

The first step to speed up the complete process is to provide the image data in digital form, e.g. by a multispectral scanner. Thus the time consuming task to digitize the photographs is avoided. The next step is to use special hardware and to optimize the software.

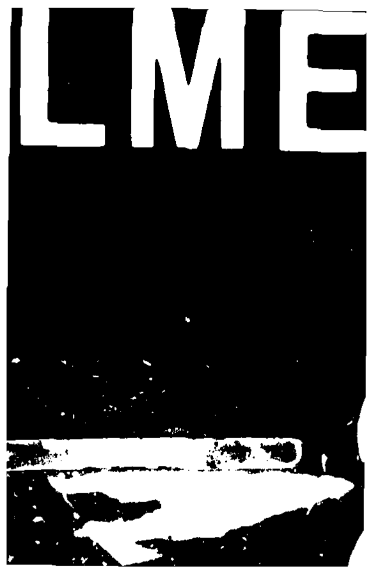
The processing times cited in chapter 5 of /1/ were obtained with FORTRAN programs which were implemented to test the methods for the extraction of linear features on a DEC PDP 11/70 and a DEC VAX 11/780. An optimisation of these programs (e.g. optimisation of the data transfer disk-memory and v.v.) would yield time saving of approximately twenty per cent.

Most of the computations can be performed on an array processor (e.g. Floating Point Systems AP 120 B), where the software has to be adapted according to the demands of the AP. Though the computations are highly data dependent and the advantages of the AP cannot be profited best, the run time without I/O would decrease by factor two to three. In comparison to the VAX the data transfer disk-memory and v.v. can be speeded up by factor two, if a disk storage is connected directly to the AP. The next possibility is to use several array processors, where each AP processes one subimage of the mosaic. For example, the estimated average processing time achievable with two APs would be less than 40 minutes for evaluating a complete aerial photograph.

References

/1/ Bausch, U. et al. Automatic extraction of linear features from aerial photographs Final technical report FIM report No. 91, Karlsruhe, 1981

/2/ Nagy, G. Wagle, S. Geographic data processing ACM Computing surveys vol. 11, No. 2, June 1979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