# HIMI - A Program Package for Height Interpolation with Consideration of Morphologic Information

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Abstract

The principle,structure and high efficiency of HIMI, a program package for height interpolation with consideration of morphologic information,are presented in the paper.The morphologic information here means topographic points,breaklines,formlines and borderlines. Two important programs of HIMI are ARRANGE,the program for data division and sorting,and INTM,the program for height interpolation with consideration of morphologic information. Based on the Graph Theory and Data Structure ,HIMI is carefully compiled. Three DEMs of three simulation surfaces and a DEM on the scale of 1:5000 for the airphoto pair of Test Area Drivdalen in Europe have been interpolated by HIMI. The result shows,that HIMI is efficient and practical for large scale DEM interpolation. Further research and development of HIMI can be expected.

## 1. INTRODUCTION

The existing interpolation methods represent terrain surfaces by some forms of polynomials/1,2/,which have continuous derivatives of higher order. With the least squares prediction method, terrain surfaces should be isotropic and ergodic stationary stochastic processes,and correlative/3,4/. With the method of finite elements terrain surfaces should have continuous derivatives of second order/5,6/. But in fact real surfaces are not very smooth and even somewhere not smooth or not continuous. On maps there exist some areas,such as lakes and resident areas,throuth which contours should not go. Therefore,if we produce DEM by using the existing interpolation methods without considering morphologic information ,we can only have low DEM accuracy and reliability.

From the birth of DEM on the significance of morphologic information has been realized/7/, and topographic points were sampled and integrated into DEM interpolation as additional information/7,8,9/. Since the middle of the 1970's,DEM interpolation with the other morphologic information i.e. borderlines,formlines and breaklines has been taken into account increasingly. At present,both in Europe and in North America there are a number of efficient and practical software systems/5,10,11/,e.g. SCOP,HIFI,SORA,CIP and TASH etc. In China,however,such a system has not been reported before the work in this paper.

In this paper the program package HIMI for DEM interpolation with consideration of morphologic information is introduced, which is compiled in FORTRAN IV on a mini-computer Nova 3. The two main parts of HIMI are the program ARRANGE for data division and sorting and the program INTM for DEM interpolation with consideration of morphologic information. In order to decrease the computing cost and increase the efficiency,a series of methods are presented here: two levels' screening method for data division and sorting; binary tree method for fast determination of subareas' boundaries,based on Graph Theory and Data Structure Theory; multi-points judgement method for treatment of interpolation with borderlines and data division and sorting for points in subareas. The interpolation method in INTM is the moving average method with polynomials of not more than second order. When interpolating DEM, the program selects corresponding algorithms -- polynomials of corresponding order automatically,according to densities and positions of data points. Besides,HIMI has colorful plotting functions for editing and checking.

Here three simulation surfaces and an airphoto pair of Test Area Drivdalen in Europe have been used to prove the efficiency and practicability of HIMI for large scale DEM interpolation.The height differences and slopes of the four surfaces are very big.The result shows that the height interpolation of a point takes HIMI 0.6 seconds averagely without morphological information, 1.0 second averagely with morphologic information. For the DEM on the scale of 1:5000 interpolated by HIMI,the RMS is not larger than 1.0 meter.

Recently,HIMI has got new development. The program versions of HIMI in FORTRAN 77 on computers PRIME 9650 and VAX 11/750 have been completed and their efficiency has been raised further. As to application,HIMI will be used to provide 1:50,000 DEM for the national land information system and the data sources are profile scanning data for the production of 1:10,000 orthophotomaps, with the investigation into practicability being finished.

## 2. PRINCIPLE AND STRUCTURE

### 2.1 Principle

When there exist breaklines and borderlines in a surface to be interpolated,the whole area coverd by the surface can be divided into a number of subareas,the boundaries of which are made up of these lines. In this case the surface is smooth only on these sub-areas and on their boundaries the surface is not smooth and continuous. Actually the DEM interpolation with consideration of morphologic information is to approximate the surface subarea by subarea by using an interpolation method, which corresponds to the treatment of non-isotropism,non-smoothness and non-correlation or weak-correlation in the surface.

The DEM interpolation procedure is as follows: first a rectangular area to be handled is divided into overlap computing units -- total computing units(TCU),as shown in Fig.1;then DEM is interpolated by HIMI TCU by TCU. If breaklines or borderlines go through a TCU, it will be subdivided into several subareas on which the surface to be interpolated is smooth only(Fig.2) and DEM interpolation is done subarea by subarea in this TCU.

The interpolation method in HIMI is the moving average with polynomials of not more than second order,and it can choose one of the following weight functions:

$$P = \exp\{-a(D/Do)^2\} \qquad (1)$$

$$P = \begin{cases} 1-2(D/Do)^2 & D \leqslant 0.5Do \\ 2(1-D/Do)^2 & D \geqslant 0.5Do \end{cases} \qquad (2)$$

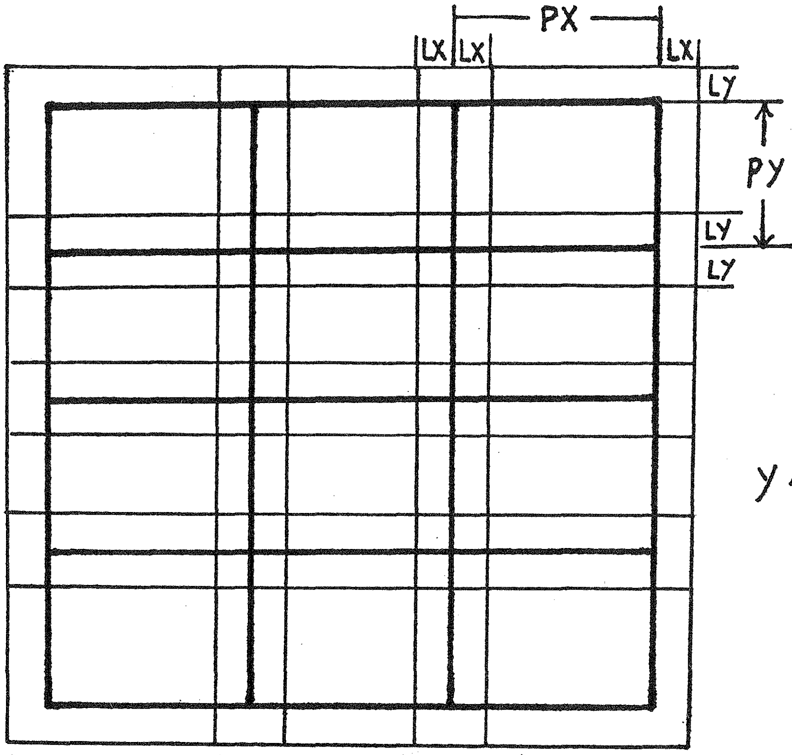



Fig.1 A rectangular area is divided into TCUs

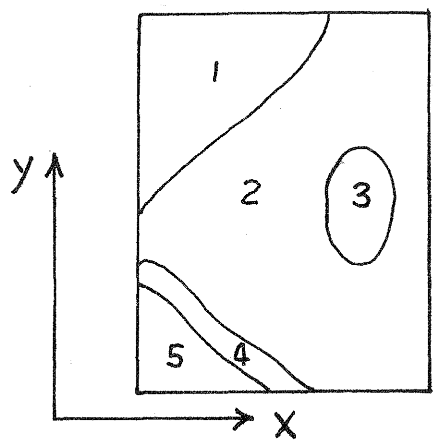



Fig.2 4 lines divide the TCU into 5 subareas

$$P = 1/D^2 \qquad (3)$$

where,D is the horizontal distance between a data point and a point to be interpolated,which is used as a coordinate origin, and Do is the radius of a limit circle -- limit distance(Fig.3).The orders of polynomials vary from zero to two automatically,according to the number and positions of data points in the limit circle, which is divided into eight fan-shaped areas in Fig.3.

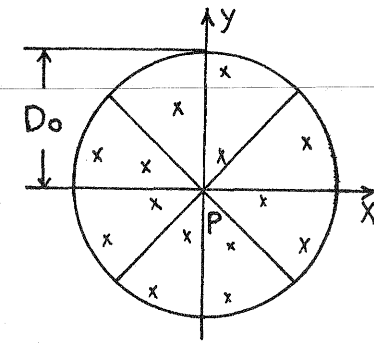



Fig.3 Principle of interpolation

In order to maintain the terrain accuracy of original data, morphological information is integrated into DEM interpolation and it has a larger weight than usual reference data.In this paper,morphologic information is divided into four classifications:topographic points, formlines,borderlines and breaklines. It is not necessary to generate DEMs in areas surrounded by borderlines.

## 2.2 The Program Structure

Fig.4 is the program flow chart of HIMI. RAG1 or RAG2 is used to transform data in ASCII to data which can be recognized by FORTRAN IV on Nova 3. RABOR is a program for absolute orientation, and EDPLOT and EFEAT are the programs for data editing and format transformation. EFEAT can do the interactive editing of morphologic information. ARRANGE is the program for data division and sorting, which groups and gathers reference and morphologic data in terms of TCUs(Fig.1). INTM is the program for DEM interpolation, PGM for perspectives, and ESTIM for accuracy evaluation. HIMI can delete repeated reference and morphologic points and generate a variety of plots which can be used to check and edit the treatment of morphologic information.

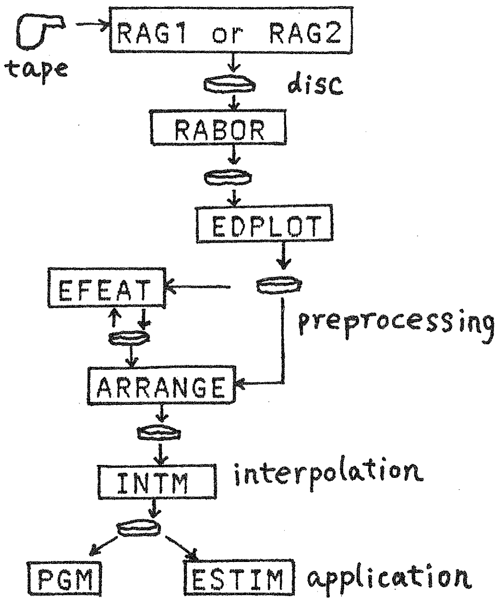



Fig.4 The program structure of HIMI

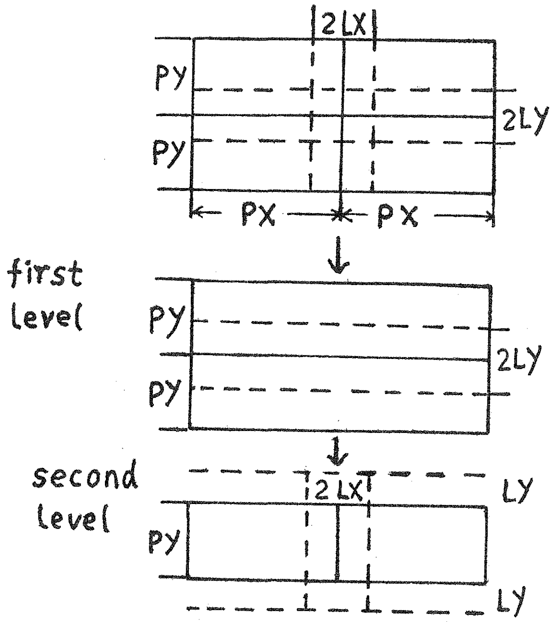



Fig.5 Two levels' screening method

The techniques of Data Structure and programming optimization have been widely and effectively used for the development of HIMI, and therefore, proper and satisfactory arrangement of the consumption of storage and time has been reached.

## 3. KEY TECHNIQUES IN HIMI

### 3.1 The Algorithm of ARRANGE

Data division and sorting before actual DEM interpolation aim at improving efficiency and saving consumption. Here two levels' screening method is presented for this task and its algorithm is as follows(Fig.5). The first level screening is carried out in Y-direction and it has a "screen":

$$\begin{cases}(i-1)PY-LY \leqslant Y \leqslant i \times PY+LY \\ -LX \leqslant X \leqslant KX \times PX+LX\end{cases} \qquad i = 1,\cdots,KY \qquad (4)$$

The second level screening is carried out in X-direction and its "screen" is just a TCU:

$$\begin{cases}(j-1)PX-LX \leqslant X \leqslant j \times PX+LX & j = 1,\cdots,KX \\ (i-1)PY-LY \leqslant Y \leqslant i \times PY+LY & i = 1,\cdots,KY\end{cases} \qquad (5)$$

where, $PX \times PY$ is the size of a computing unit(CU), $(PX+2LX)(PY+2LY)$ is the size of a TCU, and $KX \times KY$ is the number of CUs. The computing times of this method are :

$$T1 \leqslant 2n(KX+KY) \qquad (6)$$

where, n is the number of data points to be handled. The four other methods also have been investigated for this purpose and their computing times are :

$$\begin{cases} T2 = 4n\times KX\times KY \\ T3, T4 \leqslant 4n\times KX\times KY \\ T5 \leqslant 2n(KX\times KY-1) \end{cases} \qquad (7)$$

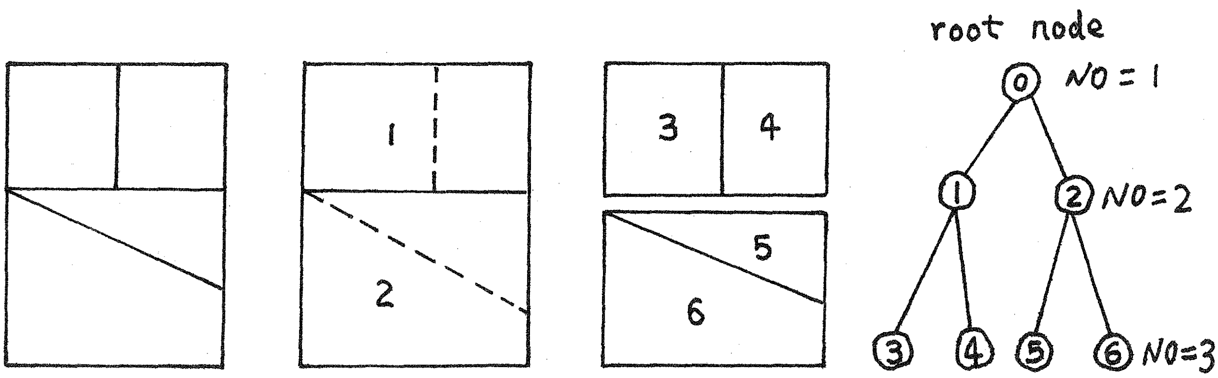
It is very clear that two levels' screening method is more efficient than the others.

After data division and data sorting, the repeated reference data points will be deleted, and morphologic information will be rearranged so that morphologic lines or points falling into a particular TCU can be found out.

3.2 Binary Tree Method for Boundaries of Subareas

Literature /15/ discussed two methods for the determination of boundaries of subareas in terms of Graph Theory, which have some limitation and can not be realized on computers very efficiently. Based upon the method of single link loop sets in literature /15/ and Data Structure, binary tree method is presented here to deal with this problem. The theoretical analysis has pointed out that the consumption of time and storage is inversely proportional to $2^m$(m is the number of morphologic lines in a TCU) with this method and the efficiency will be improved greatly with m increasing/20/. It has been concluded also that this method is more efficient without the limitation the methods in literature /15/ have/20/. A brief introduction to the algorithm and data structure of the binary tree method is given as follows.

There are three morphologic lines in the TCU shown in Fig.6(a),




(a) (b) (c) full binary tree
Fig.6 data structure of binary tree method

which is resolved as Fig.6.(b). With each resolution two subareas are got and the final result is a full binary tree in Fig.6(c). That is,the data structure of the method is a full binary tree and the leaf nodes of the tree are just the subareas we want. If the result of resolution is a complete binary tree, it should be modified by disposing nominal nodes to make it become a full one as shown in Fig.7.

The algorithm of the method is just how to determine the two sub-areas of a basic graph which consists of two subareas(Fig.8) and get their boundaries. First the incidence set of the basic graph

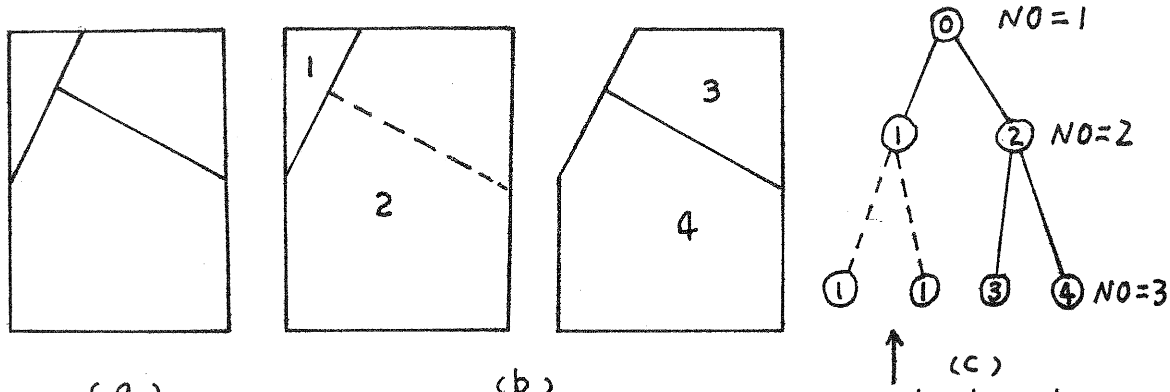
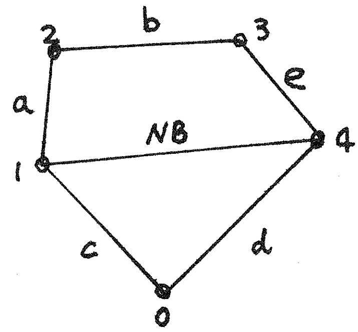



Fig.7 turn a complete binary tree into a full one

should be determined, which is a matrix of Nx3 degree (N represents the nodes' number of the basic graph) and only has two non-zero elements in its third column as in a basic graph only two nodes are incident with three edges. Then starting with one of the two nodes incident with the division edge (edge NB in Fig.8), the incidence set is searched until the boundaries of each subarea are found out. Because a basic graph is quite simple, the above algorithm can be carried out on computers very fast.




NB -- division edge

Fig.8 basic graph

3.3 Multi-Points Judgement Method

In several programs of HIMI, there exist the places where it is required to judge into which subarea a data point falls, such as when treating the interpolation with borderlines in ARRANGE and when determining boundaries of subareas and making division and sorting of data in subareas before actual DEM interpolation in INTM. Here the multi-points judgement method is introduced to solve this problem. In Fig.9, C is the boundaries of a subarea and a, b, and d are points to be judged. Let line $X=X_a$ intersect C and k be the number of the intersection points under the below constraint :

$$Y \geqslant Y_a \tag{8}$$

where, "=" means points on C such as d are not in C. If k is odd, a is located in C, and if k is zero or even, a is not located in C.

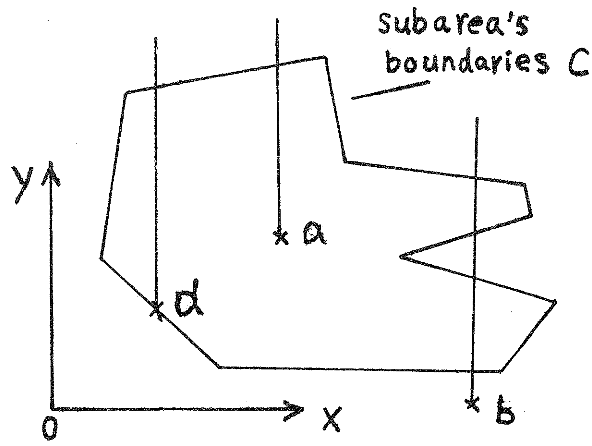



Fig.9 Multi-points judgement method

4. EXPERIMENTS

The DEMs of four surfaces with morphologic information have been interpolated by HIMI,of which three were simulation surfaces and the other one was real topographic surface. From the four surfaces the profile scanning data and morphologic data were sampled as the original data for DEM interpolation. The result has proved that HIMI is correct and efficient.

In simulation surface I there are two breaklines and its height is 160 and maximum slope 70°. In simulation surface II there are three breaklines and in one of them the surface is vertically broken. It has a height of 100 and maximum slope of 50°. In simulation surface III there are four breaklines(also in one of them the surface is vertically broken) and one borderline. Its height reaches 140 and maximum slope 70°. The accuracy analysis and time cost are shown in Table 1. For the DEM interpolation with or without morphologic data the height residuals having biger absolute values are distributed around morphologic lines. For the interpolation without morphologic data considerable systematic residuals occur around morphologic lines.

Six test areas were selected on a comparative test of photogrammetrically sampled DEMs sponsored by Co.III of ISPRS,and one of them called Drivdalen,which has the most rugged, steep and difficult terrain/21/,has been adopted here for the experiments. The area is coverd by an airphoto pair with a format of 23x23 $cm^2$,photo scale of 1:17,000, flight height of 2,550 m and focal length of 153 mm. The height difference of the area is up to 700 m and average slope 30°. The data in area 1670x1510 $m^2$ was collected on a Wild AG1-EK22-PE2, together with 13 morphologic lines and 40 topographic points.After preprocessing -- format transformation,absolute orientation and

Table 1 accuracy analysis and time cost

| surface / indicators | simula. surface I | | simula. surface II | | simula. surface III | | terrain surface in Drivdalen Area |
|---|---|---|---|---|---|---|---|
| | with morpho informa. | no morpho. informa. | with morpho. informa. | no morpho. informa. | with morpho. informa. | no morpho. informa. | |
| No. of posi. resi. | 375 | 414 | 229 | 288 | 34 | 122 | 650 |
| No. of negt. resi. | 103 | 155 | 115 | 191 | 230 | 190 | 574 |
| No. of zero resi. | 377 | 286 | 459 | 324 | 167 | 129 | 6375 |
| mean of residuals | 0.011 | 0.004 | 0.002 | 0.378 | -0.010 | -0.441 | -0.004 mm |
| RMS of residuals | 0.022 | 0.480 | 0.009 | 3.009 | 0.018 | 8.762 | 0.288 mm |
| stand. deviation | 0.020 | 0.480 | 0.009 | 2.987 | 0.015 | 8.761 | 0.288 mm |
| maximum residual | 0.11 | 3.17 | 0.07 | 24.85 | 0.04 | 60.22 | 3.27 mm |
| minimum residual | -0.06 | -2.75 | -0.04 | -2.45 | -0.04 | -33.23 | -11.22 mm |
| grid size of DEM | 2x2 | 2x2 | 2x2 | 2x2 | 3x3 | 3x3 | 4x3 $mm^2$ |
| sampling interval | 4x5 | 4x5 | 5x5 | 5x5 | 6x5 | 6x5 | 7.2x5 $mm^2$ |
| time cost of ARRANGE | $28^s$ | $28^s$ | $21^s$ | $21^s$ | $21^s$ | $21^s$ | $9^m13^s$ |
| time cost of INTM | $10^m13^s$ | $9^m02^s$ | $9^m48^s$ | $7^m29^s$ | $8^m44^s$ | $4^m22^s$ | $151^m06^s$ |
| average time cost of a grid point | $0.7^s$ | $0.6^s$ | $0.7^s$ | $0.6^s$ | $1.2^s$ | $0.6^s$ | $1.2^s$ |

interactive editing,there were eight lines left(Fig.10). The pre-processed data was computed by HIMI to produce 1:5000 DEM consisting of 7857 points and the relative accuracy analysis is shown in Table 1,which was done by taking the DEM interpolated without morphologic data as "ground truth",and the corresponding residual histogram is shown in Fig.11 with the unit of residuals being 1/100 mm. The figures in Table 1 and Fig.11 have been scaled onto 1:5000.

The residuals of larger absolute values are distributed around morphologic lines and their number is small. In the areas on which no influence of morphologic data exists,the height residuals are equal to zero. The estimation in terms of the RMS in Table 1 says the final RMS of residuals for 1:5000 DEM will not be biger than 1.0 m.

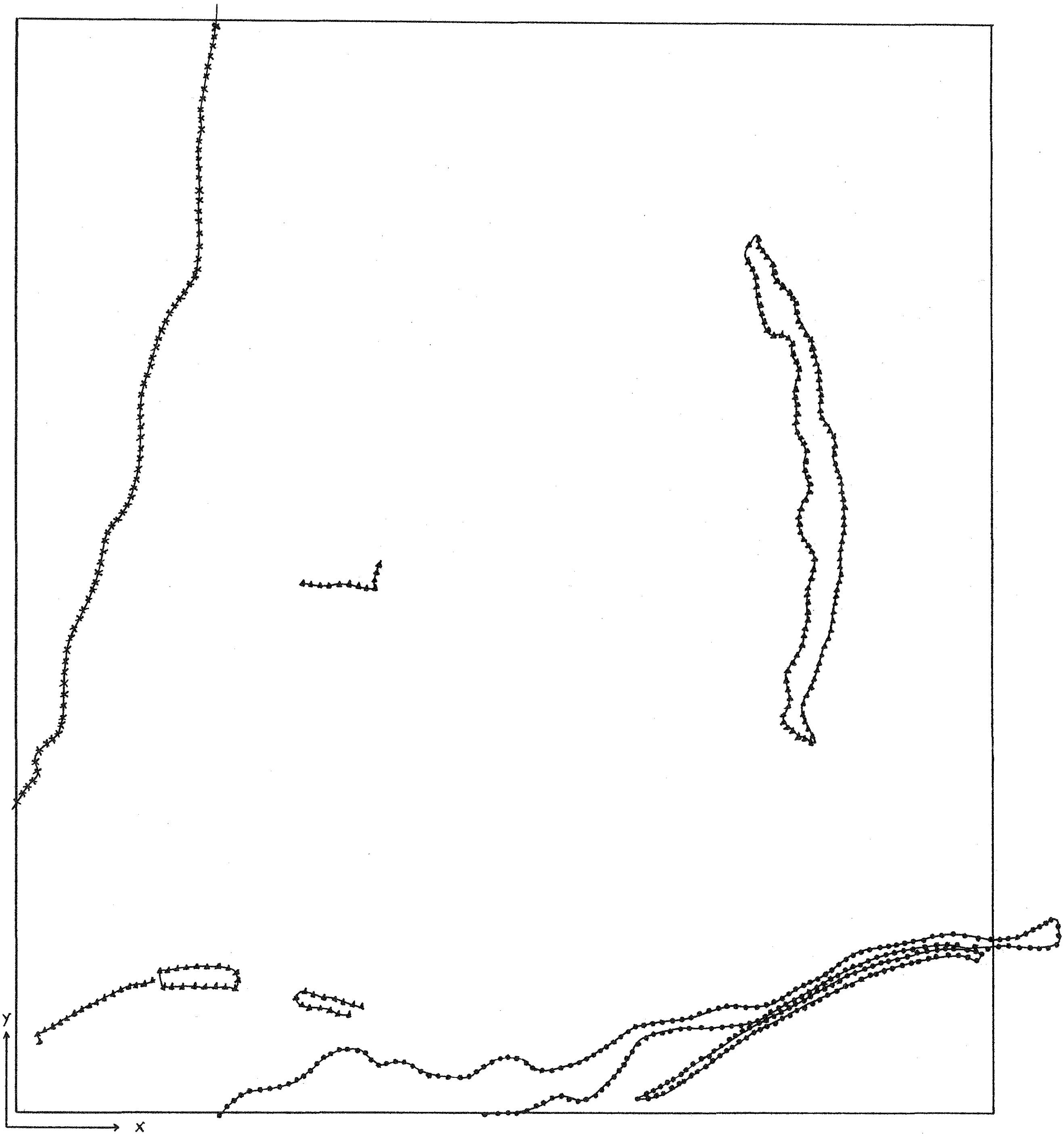



Fig.10 Morphologic lines in Test Area Drivdalen

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residuals  frequency
  -51.0      16.0  *
  -37.0      37.0     *
  -23.0      68.0       *
   -9.0     279.0  x      *
    5.0    6856.0  xxxxx*xxxxxxxxxxxxxxxxxxxxx
   19.0     138.0  x     *
   33.0      59.0     *
   47.0      29.0  *
   61.0      19.0  *
```

x - histogram  * - normal distribution with the same variance

Fig.11 Residual histogram for Test Area Drivdalen

## 5. DISCUSSION AND FURTHER WORK

Although the height differences and slopes of the four surfaces selected in this paper are very big,satisfactory results have been acquired,which indicate the correctness,efficiency and practicality of HIMI. It may be concluded that DEM interpolated by HIMI can also approach the suaface with enough accuracy as long as the data sampled in a surface represents the surface correctly (with enough accuracy).

Recently,HIMI has got new development. The program versions of HIMI in FORTRAN 77 on computers PRIME 9650 and VAX 11/750 have been implemented with further optimization and higher efficiency. Now the time spent for the interpolation of a point with the version on PRIME 9650 has decreased to 0.06 seconds. Besides a program for automatic generation of parameters has been developed, which can give optimal parameters for sampling area and interpolation. As to application,HIMI has been used to investigate into the project "the generation of 1:50,000 DEM from the data for the production of 1:10,000 orthophotomaps" and will be used to provide 1:50,000 DEM for the national land information system.

Now we are going to build the version of HIMI on micro-computers (IBM-PC) and develop DEM management and application programs. In addition,we are going to try the interpolation of non-topographic data with HIMI in order to examine the application possibility in this field. At the same time further extension and improvement of HIMI can be expected also.

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