Sub-pixel accuracy in the geometrical correction of AVHRR data

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Abstract : Satellite imagery can be geo-referenced to approximately pixel accuracy as a fairly standard procedure using a set of ground control points (GCPs) identified in both an image and on a map. We have adopted a method which was developed by Torlegård, using extracts or chips from airphotos to achieve an accuracy of 10-20% of pixel-edge accuracy for Landsat data, to attempt to achieve sub-pixel accuracy for the geometrical rectification of AVHRR data. The results show that our procedure can achieve an error of 26 % of the instantaneous field of view (IFOV).

1. Introduction

The conventional methods which are available for geometrical rectification include (i) the use of orbital models and (ii) the use of sets of ground control points (GCPs). In the past the former has usually been used when results are needed quickly but not to high accuracy, while the latter has tended to be used for cases where very accurate results are needed.

Torlegård (1986) used airphoto chips for ground control points to rectify Landsat MSS data and achieved an accuracy of about 20 % of the IFOV. Our adaptation of Torlegård's method is to use Landsat MSS chips to improve the accuracy of rectification for AVHRR data. This paper will concentrate on how to acquire reference coordinates for each chip and mention an improved algorithm for geometric correction.

2. Image to master image rectification within one pixel accuracy

We describe two approaches that we have used. The first relies on an operator to identify a small number of GCPs in both the master and the slave image. The second proceeds totally automatically without the need for any operator involvement.

2.1 Original method

One AVHRR image of the U.K. has been rectified by using 200 GCPs and resampled with a pixel size 1 km by 1 km by using cubic convolution. This image can be used as a map or as a master image for further rectification of other images. A library of about 337 GCPs has been collected manually and all of these GCPs are of known ground and image coordinates.

In its original form for rectifying a slave image to this master image our method required the operator to identify three pairs of points in the master image and slave image and then the rest were left for automatic relocation. The reason that it needs some points to start with is due to the least squares method which requires more than two corresponding points to determine the transformation parameters (rotation, scaling and translation) and uses the inverse form of these transformations for finding the approximate coordinates of subsequent points. So these points should be good enough to calculate all the required parameters which can represent the distortion of the satellite image. If the estimated point is too far from the actual point it can lead to misregistration if the searching window is not large enough. But if the

window is too large it will require a large amount of computer time, which is inefficient. To avoid this problem demands good starting points; the better the starting points, the more accurate is the approximation for further points and the smaller is the total amount of computer time needed to achieve a given order of accuracy. For AVHRR imagery the greatest distortion is in the off-nadir position, so the best suitable points to start with are in the form of a triangle (middle, extreme left and extreme right).

The searching to locate a ground control point in the slave image is done by moving the master chip (size 11 x 11 pixels) in a window (e.g. size 52 x 52 pixels) in the slave from top left to bottom left, then stepping to the next column (shift to the right) and repeating the process until the whole window has been covered. In order to obtain an increase in the correlation accuracy the searching window is preprocessed by using a low-pass filter. This preprocessing technique uses a kernel of size 3 x 3 for convolution with the searching area. Although a low-pass filter blurs the image, it preserves the low-frequency features and also gives very high improvement in accuracy especially when images have a low signal-to-noise ratio. After preprocessing, shape matrices are obtained by transforming the shape into a binary matrix. This is followed by the use of EXCLUSIVE-OR with these matrices to test the similarity between two shapes and then the cross correlation is calculated only when the shape similarity is more than some threshold value. If any point has a correlation coefficient less than 0.5, this is considered not satisfactory. This method has been shown to work quite well with a standard error of about 80 - 100 % of the IFOV and with a reasonable use of computer time. Table 1 shows some details for the registration of one image with a master chip size 11 x 11 and searching area size 52 x 52; For each ground control point in the slave image the pixel and line number obtained from the orbital model, from the shape similarity test and (when used) from the cross correlation are given.

2.2 Improved algorithm

This method eliminates completely the need for manual identification of the first three GCPs. The concept of this new algorithm consists mainly of the following components :

- Orbital model
- Library of ground control points
- Image preprocessing
- Conversion to binary image and shape similarity
- Correlation

(see Fig. 1 for the flow diagram). In order to achieve fully automatic implementation and to reduce the size of the searching window, an orbital model (Brush 1985) has been implemented by using it to give an approximate rectification and this is then followed by the use of ground control points to identify the precise position. Using the model gives an accuracy of about plus or minus 15 to 20 AVHRR pixels, but after using the first GCP the error in the rectification is reduced to about 2 to 6 pixels. The computer time,
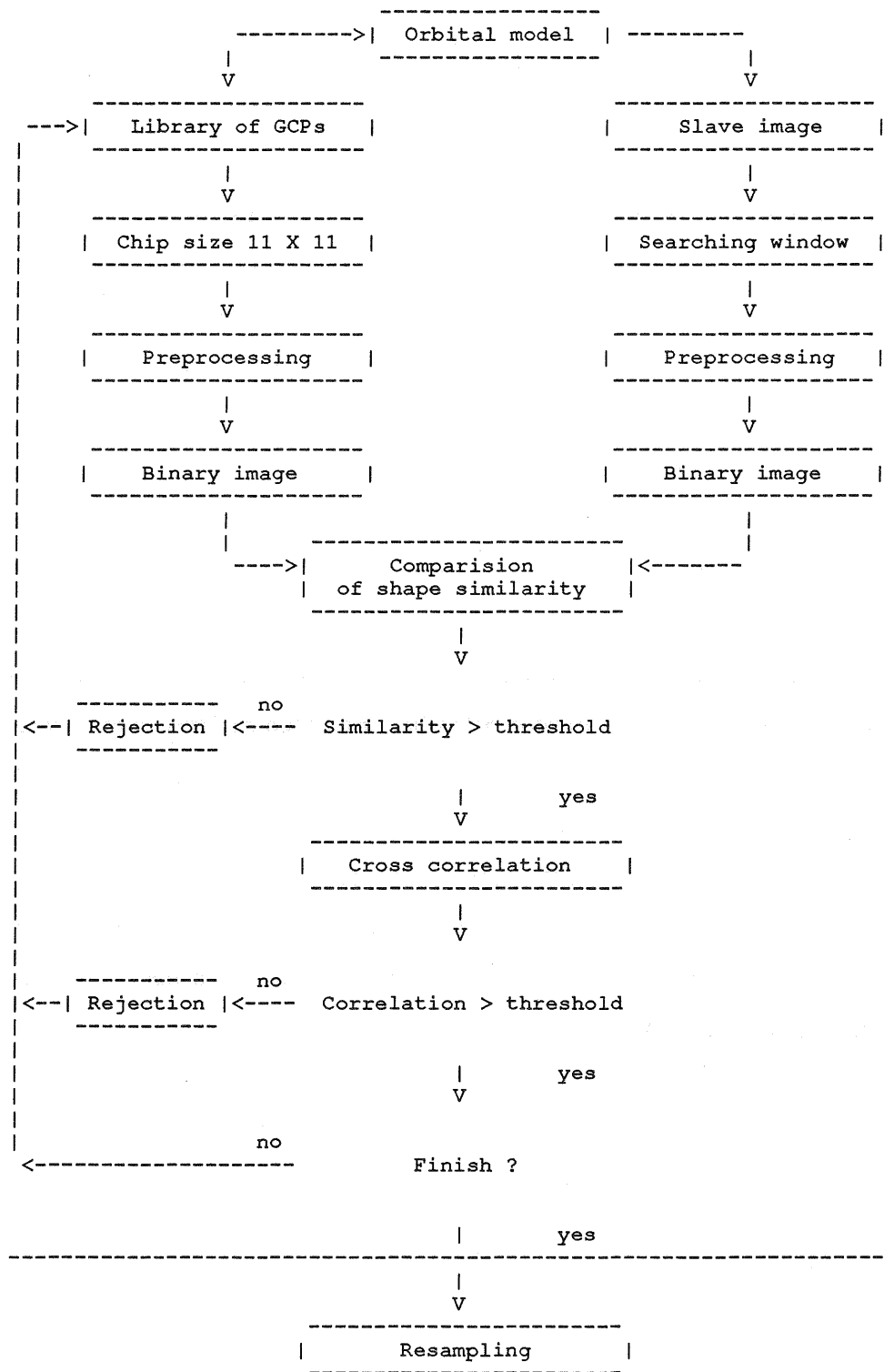
```
                              -------------------
                  --------->| Orbital model   | ---------
                  |           -------------------           |
                  V                                         V
      ---------------------           ---------------------
  --->|   Library of GCPs  |       |    Slave image     |
  |     ---------------------           ---------------------
  |              |                              |
  |              V                              V
  |     ---------------------           ---------------------
  |     | Chip size 11 X 11 |       | Searching window  |
  |       ---------------------           ---------------------
  |              |                              |
  |              V                              V
  |     ---------------------           ---------------------
  |     |   Preprocessing   |       |    Preprocessing   |
  |       ---------------------           ---------------------
  |              |                              |
  |              V                              V
  |     ---------------------           ---------------------
  |     |   Binary image    |       |    Binary image    |
  |       ---------------------           ---------------------
  |              |                              |
  |              |     ---------------------------          |
  |         ---->|       Comparision         |<-------
  |              |     of shape similarity   |
  |                ---------------------------
  |                            |
  |                            V
  |     -----------   no
  |<--| Rejection |<---- Similarity > threshold
  |     -----------
  |
  |                            |       yes
  |                            V
  |                ---------------------------
  |                |     Cross correlation    |
  |                  ---------------------------
  |                            |
  |                            V
  |     -----------   no
  |<--| Rejection |<---- Correlation > threshold
  |     -----------
  |
  |                            |       yes
  |                            V
  |                 no
   <---------------------      Finish ?


                            |       yes
  ------------------------------------------------------------------
                            |
                            V
                ---------------------------
                |      Resampling          |
                  ---------------------------
```

Figure 1: Flow diagram of the algorithm

on a DEC-10 mainframe computer, for calculating the first point for this model is about 7.7 second which is due to the iteration method for finding one parameter (the semi-major axis) but this value can be used for subsequent points, so that the time spent on the second point onward is only about 15 milliseconds.

Although it does not require an operator to locate GCPs, this method does require some user-supplied

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information, namely identification (ID) and time code for the first line of data from the header of the computer compatible tape (CCT), the equator crossing in degrees west, the orbit number and the time at the equator crossing.

This algorithm has been implemented on the University of Dundee's former DEC-10 mainframe computer and the job was usually submitted in the batch stream instead of being run interactively; this frees the user to do something else. Because with the interactive mode the elapsed time depends on the load of the computer at that moment, it can range from less than a minute to several minutes for the relocation of one point. For the registration of 293 points it took about 3 hrs 20 mins of computer time but an elapsed time of nearly 5 hrs 31 mins and accomplished an accuracy about 90 % of the IFOV.

When the process is finished, the program will be provided with the transformation which can be used for resampling the slave image to map reference coordinates. The resampling techniques are provided such as nearest neighbourhood, bi-linear and cubic spline interpolation. The fastest is nearest neighbourhood but this has less quality than the other techniques which require more CPU time.

If it is necessary to speed up the process, then a special-purpose processor such as an array processor should be used. In the early days, array processors were specially designed to deal with fast Fourier transforms (FFTs) or convolution. At present, array processors have many applications roles in image analysis, namely classification, pattern matching, simulation etc. The maximum speed is only approached when the same sequence of operation is performed on a large number of data points or a big array simultaneously. According to Strome and Goodenough (1979), the computer time is reduced by a factor in the range from 30 to 200 when compared with a general-purpose computer. Because our convolution in the preprocessing stage and repetitive arithmetic computation on the searching window are performed on each point this is an ideal case for array processors. So we hope to implement this algorithm on an array processor to speed up the process.

3. Adaptation of Torlegård's method with sub-pixel accuracy

To accomplish sub-pixel accuracy for Landsat MSS data Torlegård (1986) used airphoto chips for registration instead of Landsat MSS chips. This method can achieve an accuracy of about 20 % of the IFOV. We have adapted this method to use Landsat MSS chips to improve the accuracy of the registration of AVHRR data. Thus it is necessary to acquire Landsat MSS data for all the corresponding ground coordinates of the existing library of AVHRR GCPs and degrade them to the same spatial resolution as the AVHRR data.

3.1 Selection of ground control point

The procedure in Torlegård's method for Landsat MSS data is as follows. First, select a GCP from a digitised airphoto which is a known ground coordinate and called a control point chip (CPC); secondly,

Table 1: Use of 12 points of registration

```
Master chip size = 11 x 11

Searching area   = 52 x 52 for the first point

                 = 24 x 24 for second point onward

Identification (ID) : NOAA-9

Time code at first line of data on CCT

     Julian day    : 153

     Time of first line : 13 hrs 24 mins 34 secs

Equator crossing in degree west  :  341.11

Orbit number   :  2427

Time at equator crossing  : 13 hrs 10 mins 7 secs

Standard deviation in the x-coordinate (pixel) is 0.974

Standard deviation in the y-coordinate (scan line) is 0.704

Root mean square error : 0.849

No. of iterations : 13

No. of GCPs used : 12

No. of GCPs rejected : 1 (correlation too low)
```

no.	Master image east (m)	north (m)	Slave image Orbital model pixel	line	Slave image Shape similarity pixel	line	Slave image Correlation pixel	line	Residual pixel	line
1	147500	758750	572	377	555	394	556	394	-1.27	-0.06
2	167500	827000	598	341	600	343	600	343	0.70	-0.54
3	129250	835750	566	322	567	322	568	322	0.08	-0.98
4	246250	505250	557	641	551	637	555	640	-1.98	-1.32
5	275000	384000	541	754	541	753	540	752	-0.22	-0.11
6	294000	514750	604	647	606	648	606	648	0.99	0.73
7	264000	381500	530	753	529	752	531	751	1.65	1.01
8	312750	318250	575	764	573	763	575	763	-0.68	-0.34
9	151750	966500	634	216	634	218	634	218	-0.67	-0.03
10	156250	799500	578	361	579	364	580	364	0.65	0.75
11	161250	784500	577	376	579	378	579	378	0.43	0.36
12	138750	816000	568	342	570	343	570	344	0.53	0.93

find the image coordinates of the resampled CPC; thirdly, find the image coordinates in the weighted resampled CPC by using the weight matrix that was obtained from the point spread function of the Landsat MSS and finally use this CPC to achieve registration in the Landsat MSS data. For more details see Torlegård (1986).

When we decided to use Landsat MSS data to improve the accuracy of our AVHRR rectification, a library of control points was first set up. Landsat MSS band 7 (0.8 - 1.1 µm), which is in the near infra-red, is the best suited for land and sea discrimination. We have made a collection of ground control

points all over the United Kingdom, with about 380 points in all. Most of the points are along the coastline, since land and sea are separated quite distinctly, which is suitable for the evaluation of shape similarity. The reason for using such a large number of points is because, for any given scene, part of the area studied is almost certain to be under cloud.

For the Landsat data for each ground control point (with known ground coordinates) we can proceed as follows :

1. Resampling into pixel size of 50 m x 50 m

2. Weighting together to get size of chip 11 x 11 with a pixel size of 1 km x 1 km by using the weighting matrix that is obtained from the point spread function for the AVHRR

3. Finding image coordinates in the master image by correlation.

The summary chart of this procedure is shown in Fig. 2. This yields our final goal of obtaining for each GCP the coordinates in the master image and higher precision georeferenced coordinates which can subsequently be used for rectification of a slave image to obtain sub-pixel accuracy. See Fig. 3 for a resampled Landsat MSS chip with size 220 x 220 pixels. Fig. 4 shows the chip size 11 x 11 pixels of AVHRR data for comparision with the degraded Landsat MSS chip.

```
 ------------------------------------------------------------
|                                                            |
|   Ground coordinates in the reference coordinate system    |
|                                                            |
 ------------------------------------------------------------
                              |
                              |
                              V
         ------------------------------------------
        | Image coordinates in the Landsat chip |
         ------------------------------------------
                              |
                              |
                              V
     --------------------------------------------------------
    | Image coordinates in the resampled Landsat chip |
     --------------------------------------------------------
                              |
                              |
                              V
  ------------------------------------------------------------
 | Image coordinates in the weighted resampled Landsat chip |
  ------------------------------------------------------------
                              |
                              |
                              V
 ------------------------------------------------------------
|                                                            |
|   Image coordinates in the system AVHRR reference imagery  |
|                                                            |
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```
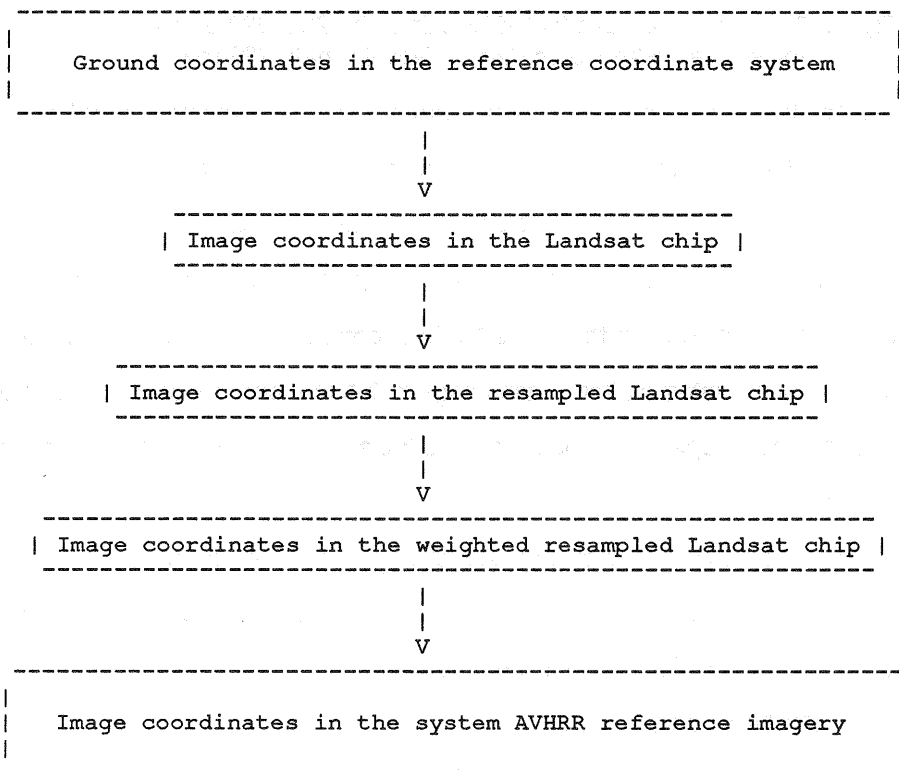
Figure 2:   Summary chart of the procedure

3.2 Location to sub-pixel accuracy

We first consider the location of a GCP chip by determining the matching position in the image to the nearest pixel, with which it has the greatest correlation. If one plots correlation (z axis) with respect to row (x axis) and column (y axis) for this searching area the matching point corresponds to the peak of the

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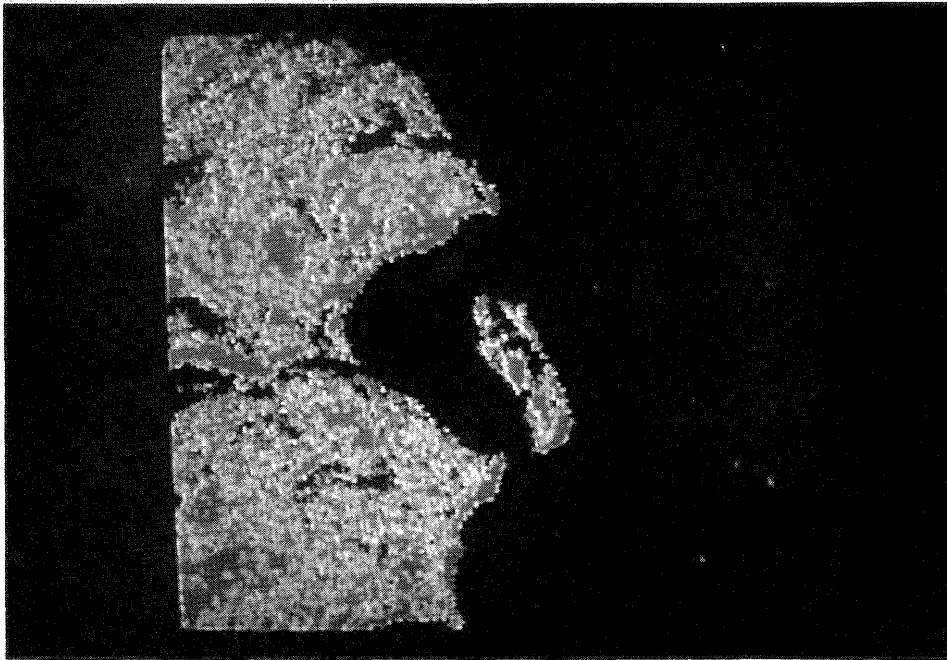
Figure 3: Resampled Landsat MSS chip with 220 x 220 pixels
(pixel size : 50m x 50m date : 5 Nov 81, path 222 row : 21)

correlation surface. Examination of the correlation values around this peak (highest correlation) indicate that they are just slightly less than the matching point. This property indicates that the highest value may be between two integer locations. So it is possible to achieve further accuracy. To do this we then start from the location of maximum correlation (peak), move the chip around in steps of one tenth of a pixel in the x and y direction and identify the position that gives the best correlation. To perform this method, due to speed and CPU time, only linear-interpolation of the image in 0.1 row and 0.1 column is implemented. If higher accuracy is required cubic spline interpolation is suitable, but it will require high computational cost as a trade-off for accuracy.

The overall accuracy can be improved with this searching for the actual peak of the correlation coefficient in terms of a fraction of a pixel, because it can locate to an accuracy of about 0.11 km (= 10 % of the IFOV) in both the x (along scan) and y (cross scan) directions.

3.3 Evaluation of the adapted procedure

A group of 7 GCPs has been selected from Landsat MSS data and processed as described in section 3.1. The result of this experiment shows that the method achieved an accuracy with a standard error of about 26 % of the pixel spacing. These are only preliminary results and we hope to be able to reduce the error below 20 % of the IFOV by using more GCPs.
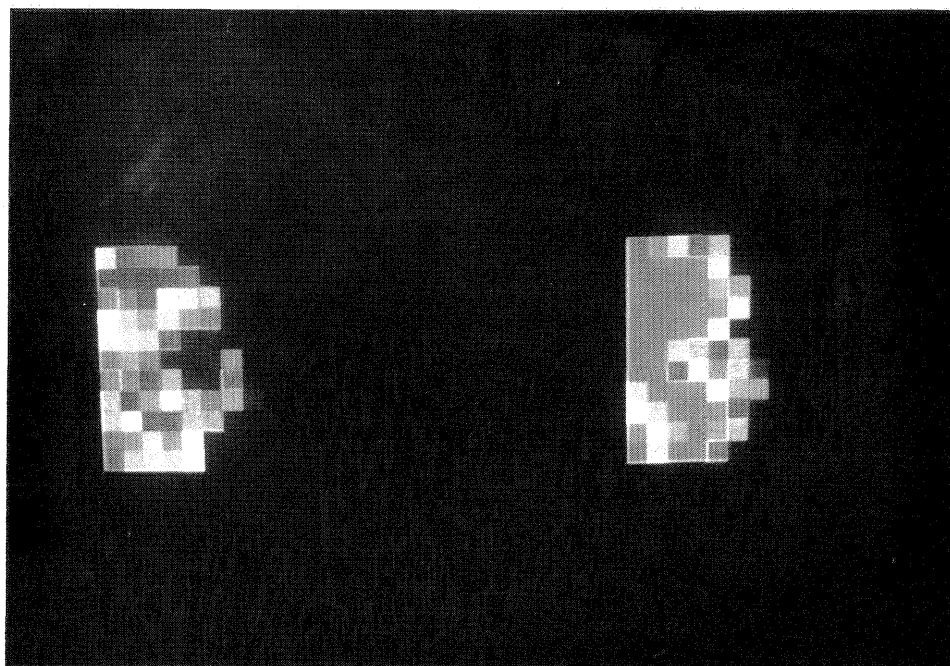
Figure 4: The chip size 11 x 11 pixels of AVHRR data for comparison with degraded Landsat MSS chip

4. Conclusion

The improved algorithm is fully automatic and achieves an accuracy within one pixel. For sub-pixel accuracy the adapted Torlegård method is quite time consuming because it needs the library of GCPs to be processed, but it is suitable if the demands for accuracy of the rectified satellite images is high. This is an obvious case for the use of parallel processing and we are hoping to extend our work in that way. With this library of control points which are known reference coordinates with precision about 20 times higher than the AVHRR ground coordinates we expect to be able to get an accuracy of better than 20 % of the IFOV.

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