Impact of Landuse Classification by Geometrical Parameters

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Abstract

Landuse classification is not yet feasible in a general, satisfactory way due to restrictions by many sources. This paper focuses paricularly geometric conditions which influences the final landuse classification result for Landsat-TM data.

The kind of preprocessing avoids radiometric problems, but yields geometric problems if their characteristics are not known and are disregarded.

If *set offs* by height differences are disregarded, general geomorphology might be corrected by polynoms, but local geomorphology will never be corrected.

The reliability and quality of the traditionell measurement of control points may be increased by tracing lines and by computing their intersections.

This methods and a sufficient number of control points yield a accuracy of rectification necessary for high level classifications.

Zusammenfassung

Die Landnutzungsklassifizierung ist aus unterschiedlichen Gründen noch nicht vollständig operationell. Dieser Artikel behandelt speziell geometrische Probleme, die die Qualität eines Klassifizierungsergebnisses aus Lansat-TM-Daten negativ beeinflussen können.

Die Art der Vorverarbeitung vermeidet zwar radiometrische Probleme, führt aber zu geometrischen Problemen, wenn man deren Eigenheiten nicht kennt und berücksichtigt.

Vernachlässigt man die Umklappungseffekte durch Höhenunterschiede, so werden allenfalls mit etwas Glück die Großformen des Geländes durch Polynome erfaßt, nie aber lokale Höhenunterschiede.

Die Sicherheit und Qualität der traditionellen Paßpunktmessung im Bild läßt sich steigern, wenn zur Markierung von Linien und Berechnung von Schnittpunkten übergeht.

Diese Maßnahmen und eine ausreichende Paßpunktzahl führen zu einer Entzerrungsgenauigkeit, die für höherwertige Klassifizierungen notwendig ist.

1 Introduction

Analysis of Remote Sensing literature shows, that geometrical questions do not seem to be any more of central interest. This was different in the 70's when "Geometry of Non-conventional Sensors" was for instance treated in a special ISPRS working group [Konecny]. Geometrical problems are generally accepted for radar systems as well as for airborne scanners. Challenges for research seem to be restricted to these two fields. Particulary the geometry of the Landsat type sensors showed a satisfactory accuracy for most applications. Very quickly after Landsat MMS launch in 1972, it was proved, that simple polynomial corrections would be o. k. for having "geometry corrected".

Nearly the same happened for the Landsat TM sensors ten years later in the 80's. The Spot sensor stimulated geometrical investigations. However, in the meantime, the questions related to these systems in the geometrical field seem to be answered. The actual research for MOMS shows the same tendency as for SPOT: Treatment and correction for the *respective individual geometry of the sensor* is developed. This is without any doubt the first very important step. But on the other hand there are basic problems still open, which are *common to all non-conventional electronic sensors* in the digital domain. Most of these problems are linked to the discrete raster geometry.

Another problem is produced by separating two different domains i.e. "Geometry" and "Semantics". In reality geometry on one side and semantics on the other side must not be separated: There is no semantics without geometry and no geometry without semantics. The intimate interrelation between the two domains is not taken into consideration up to now as it should be done.

This is of course of particular interest for a digital high quality data base. Large data bases as GIS components are more and more available worldwide. That's why with respect to these developments "Geometrical Aspects of Remote Sensing" are of outstanding actual importance.

2 Errors by Image Acquisiton

Satellite imagery do not represent images in a common sense, that means based on geometrical parameters ("central projection") valid for the whole image. Any image line possesses its own central projection for opto-mechanical scanners, rigorously spoken, any pixel. The geometrical relation between the single image lines result from the orbit and the movement of the satellite.

These two parameters as well as earth rotation and earth curvature and some more diverse technical effects have been principally corrected for the image products delivered by the ground station Fucino/Italy [Fusco]. Nevertheless resampling was only done by nearest neigbourhood. This really gives the advantage that colours stay as they originally were but the disadvantage, too, that pixels afterwards may have a geometrical error up to half a pixel. Due to scale adaption this effect leads to double lines and columns in our latitude, which, however, may easily be detected. The correction is considered afterwards for the control point measurement in the image and later during the rectification process.

Figure 1 shows the effects. In the original raster (solid lines) double lines and columns are represented in hatched form, that means the respective line and the line above are double (respectively this column and the column left). Double columns go over 16 or 17 lines respectively (number of simultaneously scanned lines). This "doubling" effect may be eliminated by post-resampling of higher order. In this case the corrected dotted raster would be produced (Figure 1). By this method the geometrical position would be shifted from 0 pixel up to ±0.5 pixel close to the doubling position for x and y (mean approx. 0.25 pixel for each coordinate direction). This yields for both coordinate

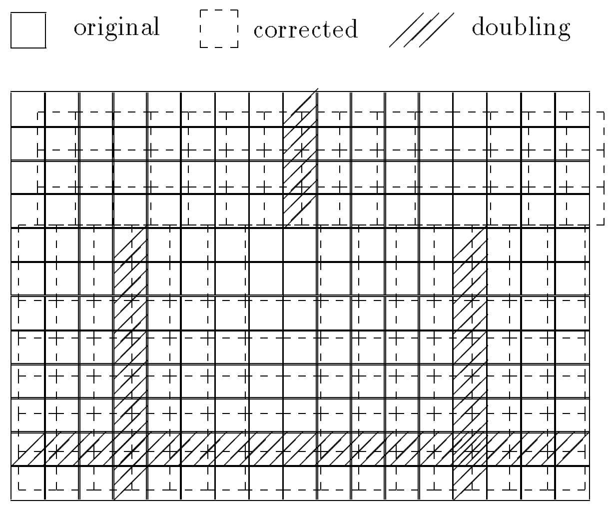

Figure 1: principle of double lines and columns

directions an expected change of position for the complete image of about 0.35 pixel (average) and a maximum shift of 0.7 pixel.

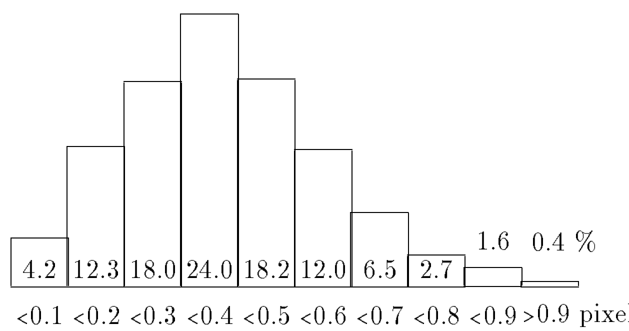

Figure 2: Control point shift by the doubling effect

In case control points are measured in the original images, the image coordinates consequently are wrong in the order of magnitude of the given numbers. In a field of 888 points of a real project, which had been measured after the method being described later on, the theoretically expected shifts were nearly exactly met: they showed a mean value of about 0.38 pixel. Figure 2 gives the distribution in percent for the single classes of the values. Due to the special measuring method, in some cases (2%), values larger than the theoretical maximum may occur.

The question arises how this effects the final result. For this reason the residuals at the control points may be compared. For an older project, based on 58 selected control points, corrections in the magnitude of the theoretically expected magnitude were produced: affin including correction ±0.38 pixel, without correction ±0.47 pixel, for a theoretical value of approx. $\sqrt{0.38^2 + 0.35^2} = \pm 0.52$ pixel. For the control field mentioned above (888 points) in a considerably larger area 464 control points were selected for the final rectification. This yielded for a poly-

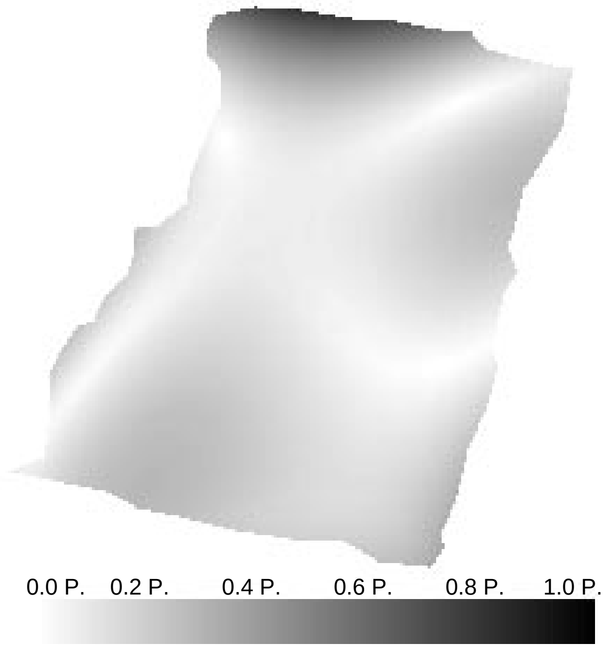

Figure 3: Rectification errors by the doubling effect

nom of third order ± 0.57 pixel (including correction) and ± 1.10 pixel (without correction); theoretically $\sqrt{0.57^2 + 0.35^2} = \pm 0.67$ pixel were computed. Taking polynoms of first or second degree the differences were somewhat smaller.

Principally the error is of systematic nature. For stochastically distributed control points one has to count with a stochastical distribution of the shift effect. This however does not exclude local clustering for just one direction. Moreover the parameters of the polynoms for rectification may be influenced. The real, practical influence of this error source may indeed be larger than it has to be expected theoretically. When comparing the polynoms yielded by computation of the parameters for rectification with and without correction, regional effects may be observed (Figure 3). Especially at the limits of the area covered by control points, up to 0.7 pixel shift (upper part) in position between rectification with or without consideration of the "doubling effect" may occur, however. In most parts of the area the differences are below 0.2 pixel.

3 Control point measurement

3.1 Measurements in the Image

The image errors treated above yielded errors in position of ± 0.5 pixel maximum for each coordinate direction; for the whole image mean errors in the order of 0.35 pixels had to be expected. This value also appears during the control point measurement. Theoretically a "point" in the object space shows a mean distance in a pixel raster to the pixel center of 0.35 pixel [Bähr 76]. For conventional ground control determination, (that means definition of a single pixel as a representative of an object like a "point"), this value represents the upper limit of the possible precision. In practise this error will be larger: Low contrast and problems assigning objects larger than one pixel and so on complicates the measurement.

A very good control point type — for regions with good infrastructure — are intersections of roads and other linear features. Although often smaller than one pixel they are mostly visible due to high contrast. Moreover they may be identified well on maps in contrast to natural objects (e. g. forest edges), which are always uncertain. However, the determination of the real intersection point by the conventional method is not always secure enough. For small lines it may happen, that they are only partly visible, for broader lines there are often many pixels involved in the intersection area. Besides that, there is still the above-mentioned limit of accuracy of 0.35 pixel.

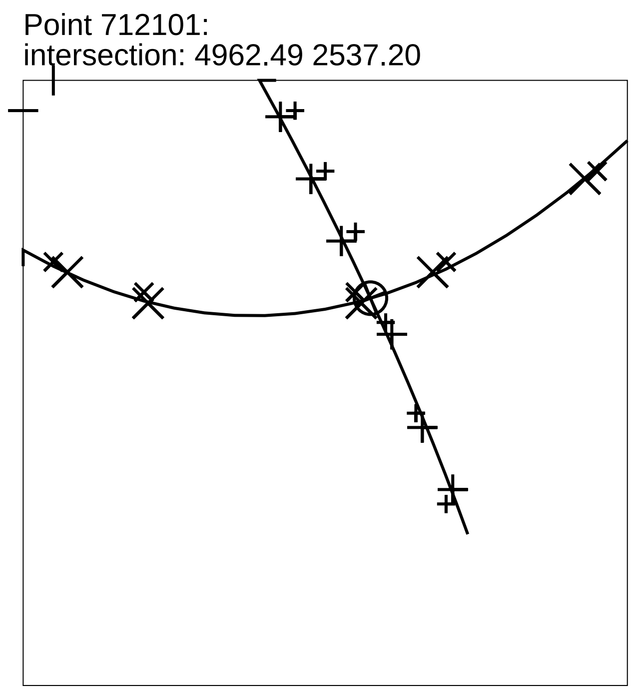

Figure 4:
Control point measurements by intersection method

In order to avoid these problems, another type of determining the intersection points is presented. Instead of more or less "estimating", the intersection points, it is proposed to measure several points of the line objects involved. These points now define a polynom of first, second or third degree (line, parable of second or third degree). If more points were determined as necessary for the determination of the polynoms, an adjustment procedure is applied. The intersection point of the two (or may be three) involved lines is then determined analytically. The determination of the intersection points by iterative methods is sufficient.

Figure 4 shows a control print of the intersection point determination. The small crosses represent the original measurements, the larger crosses the pixel positions after correction of the image errors (see also figure 1). The two roads in this case were approximated by a parabolic curve. The intersection is marked by a circle.

This procedure shows several advantages: The theoretical limit of accuracy now does not only refer to a single measured intersection point but refers to all line points. In case of lines not exactly parallel to the raster, a stochastic distribution of the error for all line points can be expected. This means reduction of the influence for the intersection point. Only line points are measured, which without any doubt are part of the "real line". Consequently line sections which are uncertain may be left out. The intersection point itself is not necessarily visible or may after all not really exist, if the map shows that the course of the lines involved may be determined sufficiently well by the polynoms. In consequence a larger number of control points is available.

In order to compare both methods as in chapter 2, a second independant measurement of the whole control point field would be necessary. Taking a selection of 42 points as a test, a difference between both measurements of more than half a pixel was shown. Increase of accuracy by computing the rectification parameters by this method, is in the order of a tenth of a pixel for these 42 points. Possibilities and limits of this method depend very much on local environment of the point; consequently there exists a restriction for applying these values in general.

3.2 Measurement in the Map

Whereas ground coodinates of control points for an older project were digitized from paper maps in 1:25000, for a recent project maps in 1:50000 were available in raster form. In this case the terrestrial coordinates may be determined in the same way as the image coordinates. 53 control points were used in both projects and determined after both methods. The terrestrial coordinates differed by 12.5 m in general, this corresponds to 0.4 pixels and 0.25 mm in the map for 1.25000 (which is approx. the precision of digitizing). Taking only these 53 points for computing the parameters of the rectification, based on both measurements, the mean square error at the digitized points is in the order of 1/100 pixel larger than for measuring in the raster maps. From the quadratic difference this yields an order of magnitude of approx. 2/10 of a pixel for this error component.

More important than the increase in accuracy however is the improvement of working conditions. Taking four identical points, an approximative relation between image and terrestrial coordinate system is established. For any object in the image it is therefore possible to give simultaneously the respective map section. This is not only comfortable and quicker, it also increases the reliability of point identification.

4 Height Correction

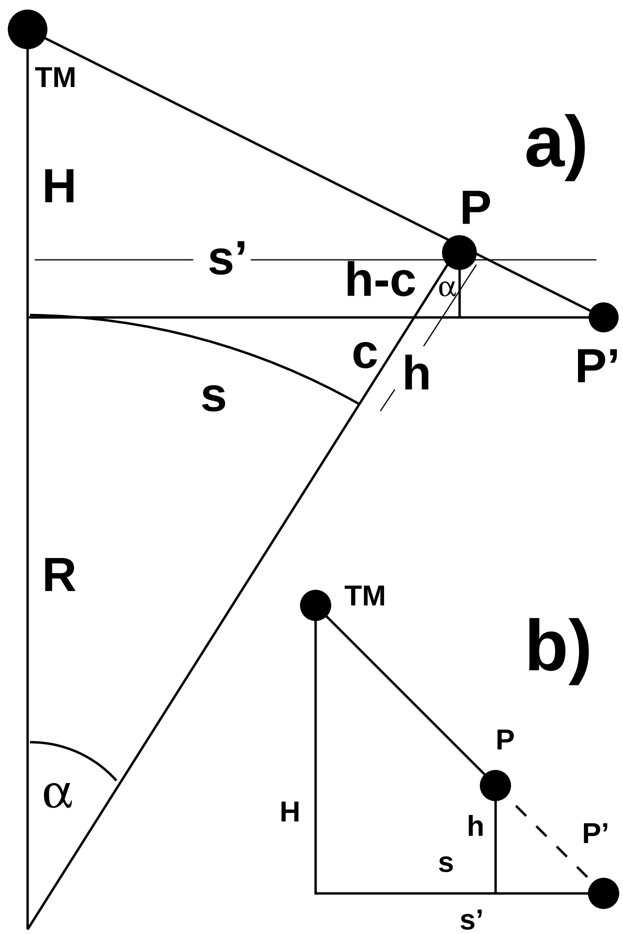

Figure 5: Height Correction

Another significant issue, which influences the geometrical accuracy, is the *height set off* of the image points. The *height set off* may be checked taking Figure 5b: Due to $\Delta s = h/H \cdot s'$ a height of 235 m at the image border leads to a *set off* of one pixel into the direction of the image border [Bähr 91]. For a more exact correction the earth curvature should be taken into account (Figure 5a). Both corrections may be simultaneously derived as follows:

The distance s' is composed by three terms:

$$s' = R \sin\alpha + (h-c)\sin\alpha + (h-c)\cos\alpha \frac{s'}{H} \qquad (1)$$

The distance c may be derived from:

$$\frac{R}{R+c} = \cos\alpha \tag{2}$$

Trigonometric series taking $s/R = \alpha/\rho$ yield:

$$\sin\alpha = \frac{s}{R} - \frac{s^3}{6R^3} + \ldots \qquad \cos\alpha = 1 - \frac{s^2}{2R^2} + \ldots \tag{3}$$

Inserting (2) and (3) into (1) leads to:

$$s' = s - \frac{s^3}{6R^2} + \frac{hs}{R} - \frac{s^3}{2R^2-s^2} + \frac{hs'}{H} - \frac{hs's^2}{2HR^2} - \frac{Rs's^2}{H(2R^2-s^2)} - \frac{hs^3}{6R^3} + \frac{s^5}{6R^2(2R^2-s^2)} + \frac{Rs's^4}{2HR^2(2R^2-s^2)} + \ldots \tag{4}$$

The last three terms are small and may be skipped. For the other terms we simplify: $2R^2 - s^2 \simeq 2R^2$ and $s' \simeq s$. The *height set off* now may be written as:

$$s - s' = \Delta s = -sh\left(\frac{1}{R} + \frac{1}{H}\right) + \frac{s^3}{R}\left(\frac{2}{3R} + \frac{1}{2H}\right) \tag{5}$$

The second term in equation (5) is the correction due to earth curvature. This term for Landsat-TM-Data in general has already been corrected. In case that it is not done, polynomials from third degree will compensate this effect by computing the parameters for rectification. Therefore only the first term, as a function of height, remains which is expanded by $1/R$ compared to the "2-D-check" in Figure 5b:

$$\Delta s = -sh\left(\frac{1}{R} + \frac{1}{H}\right) \tag{6}$$

The term $1/R$ reaches 11% of the $1/H$ term; for higher accuracy standards this should not be neglected, the more so as there is no problem in computing that value.

The *height set off* has to be considered in two different stages of the rectification: For determination of the rectification parameters and for geometrical rectification of the whole scene. The conventional method for computing the rectification parameters are 2D, i. e. height differences are not taken into account. This is why before computing any image coordinate, a control point ought to have a correction according to equation (6). The resulting rectification parameters are of course valid only for points of height = 0. Therefore each image point during the rectification process has to be corrected by equation (6).

Which are the effects of the heights which have not been considered? Taking the rectification parameters with or without height correction in the control points, this yields point errors including corrections which are some 1/100 better. A direct comparison of the rectification parameters like in figure (3) is not useful, because additionally height corrections are applied.

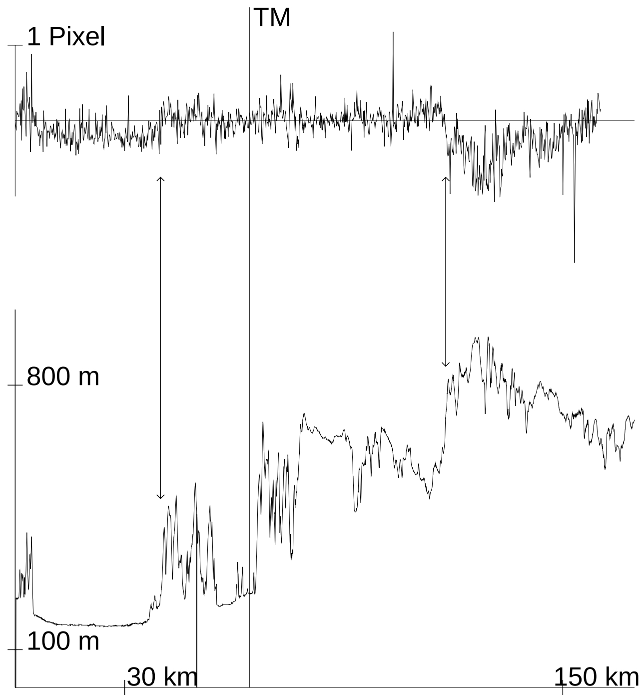

Figure 6: Errors by height set off

Finally, an image strip was completely rectified according to both methods. Afterwards by digital correlation [Piechel] the shift between both images was determined. The result is shown in Figure 6. In the lower part the height profile is displayed. On the left hand side the Upper Rhine Valley is visible, including the border of the Vosges at the very left part. The Black Forest (Schwarzwald) on the right hand side is profiled in a larger cross valley; therefore we don't get large heights here. In the right part the ascent to the Schwäbische Alb (Swabian highlands) is obvious. The vertical line througover both curves marks the approximate orbit of Landsat TM.

In the upper part the displacements between both rectifications are displayed. They show in general values up to nearly one pixel because of uncertain correlation, but they are mostly significantly lower. Therefore it may be assumed that the general geomorphology of the terrain is correctly designed by polynoms of third order.

Besides this local pertubations are obvious. After all in the curve above the ascents of the Black Forest and the Schwäbische Alb (marked by a double arrows) are visible. Here big height differences happen for a very short distance (height differences above 300 metres). Local pertubations of this kind are not modelled by polynoms. In any case they result in rectifications which are not correct.

It shows up, that polynoms do not adjust for whatever geomorphologic structure. If possible, one should therefore take use of digital terrain models (DTMs).

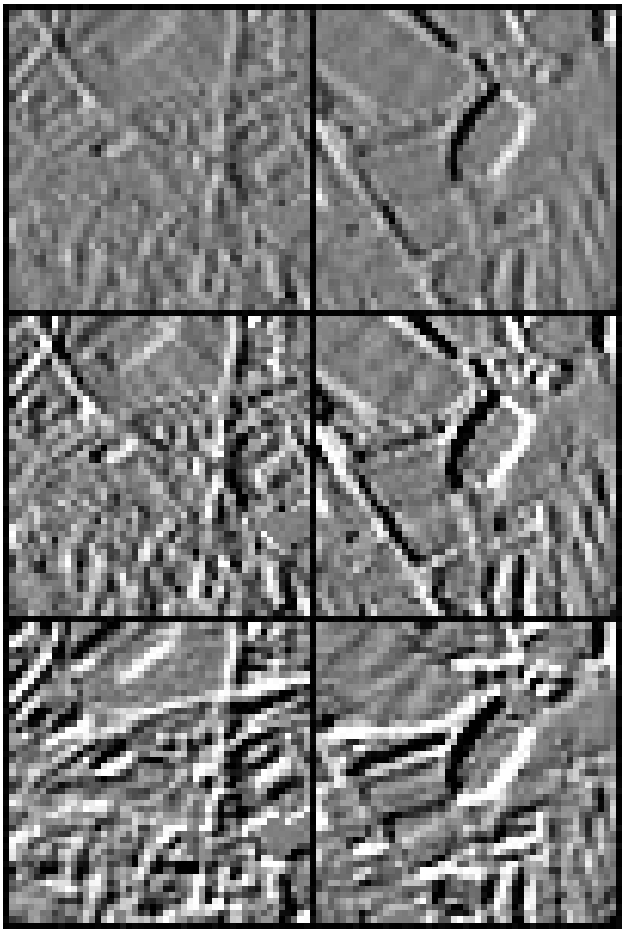

Figure 7: Simulated shifts between scenes

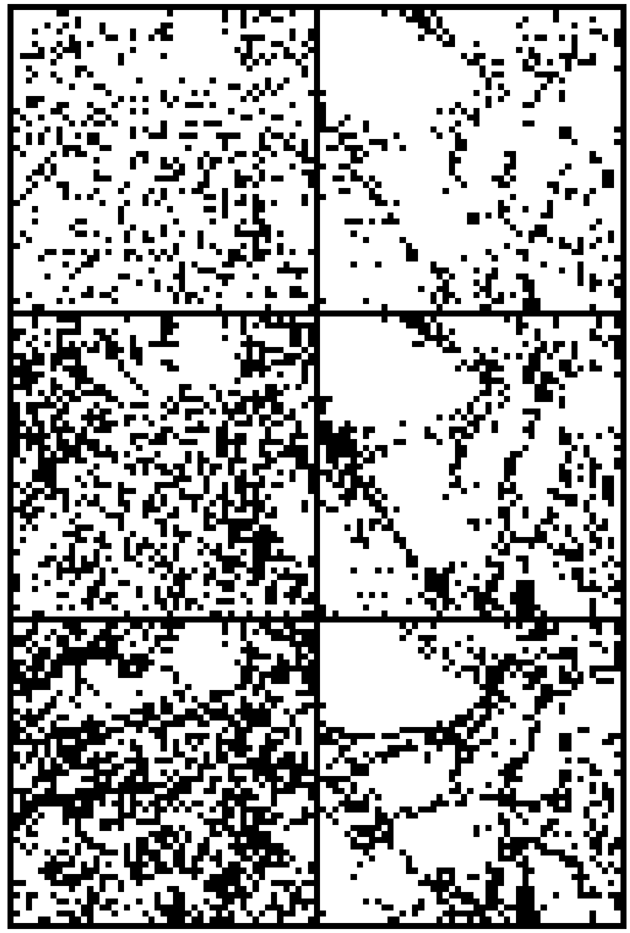

Figure 8: Pixels which changes their class

5 Impact on Classification

Simple image interpretation or classification does not necessarily require high accuracy. This is not the case for high level classifications. Here often multiple scenes of one year are used in order to improve thresholds between similar classes by phenomenological features. Several images from just one area are used for controlling landuse changes during longer periods. In Europe many areas are "mini-structured" leading to relatively high errors between multiple scenes even for small local shifts.[Baumgart]

This effect was simulated in scenes from the first project. After full correction two rectified TM scenes were shifted in an area of 20000 pixels, taking the following cases:
0.5 pixel in x, 1 pixel in x, 1 pixel in x and y.
Subtracting the corresponding channels, the original scenes were expected to show only the differences due to seasonal impact, but the shifted scenes the additional influence of the geometic error, too. Figure 7 shows the result given by the subtraction of the shifted images from the non-shifted. The three different cases defined above are displayed with two examples each time.

When classifying the respective test scenes, different results are obtained for the shifted images. As the classifications were not yet corrected by relaxation or another method, many mixed or isolated single pixels are still in. Therefore it is not really significant, that the first visual impression is showing worse results. The percentage of one class in the image regarding the three cases may oscillate a little bit, — in most cases it goes up or down continuously according to the magnitude of the shift, however, — a significant trend for a special landuse class is not obvious. It is interesting to note the number of pixels which changes classes: for a half pixel shift approx. 17% of all pixels changed; for 1 pixel 29% and for 1 pixel in each coordinate direction 35%. Figure 8 shows these effects for the same sections and cases given in Figure 7.

Another parameter proves, that the quality of the classification really deteriorated. The Mahalanobis Distances of the classifications allow to derive different quality standards to express the confidence in to the classification. The mean of one of these standards for the unshifted classified sector gives 76. For half a pixel shift this goes down to 75, for one pixel to 71 and for one pixel in each coordinate direction to 68. The confidence decreases while the shifting increases.

Therefore the geometrical interrelation between both scenes is a decisive parameter for quality. This is why images are frequently rectified relatively. Here, height errors disappear in case we use images from the same orbit. Taking images from two orbits, in the superposition area the height error is doubled of course. Instead of conventional control point measurement point transfer by digital correlation is suggested. Difficulties are produced by changed colour values and contrast as a function of the season; the advantages are possible automatic measurement of image control points, and the independance of a sufficiant availability of ground control points, For a relative rectification only the influence of image errors is fully involved, because they are different in both scenes. Only for the reference scene an absolute rectification is performed.

This method is optimal in areas where only a few control points are available in the national coordinate system. If sufficient ground control points are available one may apply an absolute rectification of all images. The precision of a relative rectification should correspond to a possible accuracy of two absolute rectifications if all mentioned corrections are applied. As ground control point coordinates in the national system do not change, they may be put into the archives. The necessary effort for an absolute rectification is comparable to a relative orientation due to fitted programs. There is no dependency on a reference scene, e. g. its image and rectification quality as well as permanent availablity on hard disk.

6 Conclusions

A conventional absolute or relative image rectification includes the following steps:

- Ground control point measurement marking specific single "points"
- Determination of the rectification parameters for polynominals of first, second or third degree
- and finally realisation of the rectification based on these parameters.

This method was extended or improved in three respects:

- The systematic image errors are determined and corrected,
- the ground control point measurements are done by intersection of line features
- errors from height components are corrected.

More steps would be feasible. Control lines instead of control points are discussed in literature. The computing methodology, however, differs very much from the presented one. The advantages of satellite imagery do not seem to be big, therefore an implementation was not performed. For the computing of the rectification parameters different methods are possible too, like polynomials of higher degree, splines or a post processing interpolation of the residuals at the control points.

The last issue mentioned is available in most programs, but here the control points are considered practically error-free and the residuals are taken as local errors of the satellite image. This assumption seems to be very optimistic because there are so many error sources in spite of correcting the coordinate measurement (e. g. generalization of maps, bad interpretation due to shadows or contrast variations). As long as there is no regional clustering of the residuals involved, a "post processing interpolation" should not be applied.

The presented methods yield ground control point accuracy of half a pixel or better as a function of the extention of the area and availabilty of ground control points. For simple image interpretation or simple classification such a quality is not necessarily required. The demands on high quality geometry increases, however, when using more rigorous methods like those described in paragraph 5, e. g. when taking several scenes for a single area.

Apart from "multi-image restitution" a high geometrical quality is necessary too, if apart from the satellite image other type of data are to be integrated into the process of rectification or classification or if the results of the restitution have to be put in relation to other data. Such data are in general given in the national coordinate system. Important additional data is for instance the digital terrain model, where apart from height correction, correction for terrain exposition may be determined. Other data type may control a classification e. g. topographic maps. This is only feasible, if the image is exactly geometrically congruent to this type of data.

Here it is shown, that traditional rectification methods may still be improved and that the additional effort is justified. Correction of the image errors does not produce significant costs, because it is computed from the image itself. In case a digital terrain model is available, the height corrections, too, do not require extensive additional work.

The most significant parameter for the rectification quality is introduced by the ground control points. Only a sufficiently big number of ground control points produces security and confidence suited to eliminate "bad" points. The number of points left over should be sufficient for detecting local pertubation of the sensor orbit as well as errors due to non-adequate models.

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