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Techniques for Estimating the Positional and Thematic Accuracy of Remotely Sensed Products

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Abstract. The aim of this paper is to review standard methods for assessing the quality control of cartographic products in the context of remote sensing. A further aim is to present a methodology to assess the positional accuracy of spatial databases using generic features (and their spatial distribution) within the image in the validation phase, and also describe a methodology that specifically takes into account spatial pattern of errors of omission and commission, in order to present the user with an indication of the reliability of the pixel label assignments. Three remotely sensed images were used in this study, acquired by the satellites Landsat, CBERS and SPOT respectively. Results show that considerable amount of research and development needs to be accomplished before the spatial characterization of positional ant thematic accuracy associated with remote sensing can be adequately reported in standardized format and legends. Several techniques for the quality control of spatial databases using generic features are adapted to the context of remote sensing, however, one drawback for some of these approaches is the difficult to obtaining homologous points in both representations. Alternative techniques to overtake such limitations are also discussed.

Keywords: positional accuracy, thematic accuracy, error, image classification, CBERS.

1. Introduction

It is widely acknowledged that classification of remotely sensed imagery has variable and often poor quality. The cause and nature of these errors has been the subject of extensive research in order to improve the accuracy of remotely sensed products. Error in this context can be defined as some discrepancy between the situations depicted on the generated image (map) and reality (Arbia et al., 1998). Performing spatial data analysis operations on data of unknown accuracy will result in a product with low reliability and restricted use in the decision-making process, while errors deriving from one source can propagate through the database via derived products (Lunetta et al., 1991). The quality of data is a function both of the inherent properties of those data and the use to which they are to be put. Hence, knowledge of error levels is necessary if data quality is to be estimated.

There are two different components of accuracy in the context of remote sensing: positional and thematic accuracy (Janssen and Van der Wel, 1994). Positional accuracy determines how closely the position of discrete objects shown on a rectified image (map) or in a spatial database agree with the true position on the ground, while thematic accuracy refers to the non-positional characteristic of a spatial data entity, the so-called attributes (which are derived from radiometric information).

Quality control of cartographic products is usually accomplished by computing the discrepancy between each member of a set of well defined points present in one cartographic document with the corresponding points observed in the field, using a technique that guarantees sufficient accuracy for the analysis. In spatial databases generated from remotely sensed data, it is equally necessary to have knowledge of the discrepancies (errors). However, in some imagery where the number of control points is not sufficient, or where their spatial distribution is not adequate, the use of generic features (such as roads, edges, polygons, etc) to provide a means of relating two spatial data sets is an important alternative.

The aim of this paper is to review standard methods for assessing the quality of cartographic products in the context of remote sensing. A further aim is to present a methodology to assess the positional accuracy of spatial databases using generic features (and their spatial distribution) within the image in the validation phase, and also present the user with an indication of the thematic reliability of the remote sensing products.

2. Study Area and Data

Two different datasets were used in order to assess the positional and thematic accuracy of remote sensing products.

2.1 Positional Accuracy

The study area is located near the town of Uberaba-MG, in southeastern Brazil. This area is located at approximately 700m above sea level, and possesses an undulating topography. The economic activities of the region are based on the milk and derived products; as most of the area is covered by grassland.

Two remotely sensed multi-band images were used in this study, one acquired by the Landsat Thematic Mapper (at 30m resolution) and the other by the High Resolution CCD Camera (HRCCC) carried by the China-Brazil Earth Resources Satellite (CBERS). This camera has a spatial resolution of 20 m. For the purposes of this study, a single waveband of each of the two multi-band images (TM and HRCCC) were used. A 1:25,000 scale map of the study region was used to provide ground reference data.

The two single-band images were geometrically registered to the UTM reference system (zone -23 S) using the Córrego Alegre horizontal datum (Brazil). Image to map registration used 14 and 12 ground control points respectively for the Landsat TM and CBERS HRCCC images, with nearest neighbour resampling, since this technique maintains the original pixel values (Jensen, 1986). In each case, the root-mean-square (RMS) error associated with registration was less than 0.5 pixels (i.e., the RMSLandsat = 0.4721 and the RMSCBERS = 0.479). Atmospheric correction was not performed since comparisons are not being made directly between images.

2.2 Thematic Accuracy

A SPOT High Resolution Visible (HRV) multispectral (XS) image (14 June 1994) of a region of flat agricultural land located near the village of Littleport (E. England) is used in this study, together with Field Data Printouts for summer 1994. These printouts are derived from survey data supplied by individual farms, and provide details of the crop or crops growing in each field in the study area. On the basis of examination of the areas covered by each crop, the geographical scale of the study, and the spectral separability of the crops, seven crop categories were selected: potatoes, sugar beet, wheat, fallow, onions, peas and bulbs.

Image processing operations were performed using ERDAS Imagine (version 8.0) and the IDRISI GIS. Neural network application used the SNNS software. Some in-house programs were written to carry out specific procedures. Registration of the image to the Ordnance Survey (GB) 1:25,000 map was performed using 17 ground control points and nearest neighbor interpolation. The RMS error was 0.462 pixels.

3. Techniques for Estimating Positional and Thematic Accuracy

3.1 Positional Accuracy

A standard method of assessing the positional accuracy of cartographic products is based on comparison of deviations between homologous control points that can be accurately located on both the reference map and the geometrically corrected image. The deviations at these homologous points are used to compute statistics that are used to perform specific tests to evaluate the accuracy of the geometric corrected image.

An alternative approach to assess the positional accuracy of cartographic products is based on the use of geometric features (Galo et al., 2001). Examples of geometric features are roads, edges, and other boundaries. They should be easily located and represented as a set of sequential coordinates in both documents (i.e., the image to be corrected and the reference map). Three feature-based methods have been used by Vieira et al. (2002) to measure the correspondence between features shown on a reference map and a remotely sensed image. These are the Generated Point Method, the Areal Method and the Equivalent Rectangle Method. As these alternatives methods work with the relative distances between homologous points, there is no need to apply trend analysis to check the presence of systematic errors on the directions E and N (E and N are the directions X and Y respectively on the Universal Transverse Mercator coordinate system). One of these methods is presented in the following sections.

3.1.1 Map Accuracy Standards (MAS) Determination

An important method for cartographic evaluations of generated maps is the use of Map Accuracy Standards – *MAS* (Galo et al., 2001), which is based on the comparison of deviations between homologous control points easily located on the reference map (X_m, Y_m) and the image (X_i, Y_i). The deviations at these homologous points ($\Delta_E = X_m - X_i$, $\Delta_N = Y_m - Y_i$) are used to compute statistics that are used to perform specific test to evaluate the trend and the accuracy of the geometrically corrected image. In this analysis it was considered that the reference map is sufficiently accurate for our purposes, i.e. to assess the geometric quality of the images.

According to Merchant (1982), the aim of trend analysis is to check for the presence of systematic errors. This check uses the sample mean of the deviations ($\overline{\Delta_E}$, $\overline{\Delta_N}$). A statistical test is applied, using the null hypothesis that the sample mean is estimating a true (population) mean of zero. If the null hypothesis can be accepted at some significance level then the conclusion to be drawn is that there is no trend or systematic error in the directions X and Y respectively.

The Student's t Test is normally used to carry out this statistical test. The critical value $t_{n-1,\alpha/2}$ is obtained from statistical tables (where n is the total number of control points and α is the confidence level, for example 0.1). If the calculated value of t for the deviations along the north-south dimension $|t_N|$ is less than $t_{n-1,\alpha/2}$ and the calculated value of t for deviations in the east–west dimension $|t_E|$ is less than the tabled value $t_{n-1,\alpha/2}$ then the generated product (e.g., image) is free from systematic errors on the directions N and E respectively. The estimated values of t_N and t_E can be estimated using the following equations:

$$t_N = (1/\sigma_N).\Delta_N.n^{1/2} \quad (1)$$

$$t_E = (1/\sigma_E).\Delta_E.n^{1/2} \quad (2)$$

where σ_E and σ_N are the standard deviations of the discrepancies Δ_E and Δ_N in the directions E and N respectively.

Accuracy analysis uses comparison of the variance of sample deviations ($\mathrm{var}(\Delta x), \mathrm{var}(\Delta y)$) to their respective pre-defined (tabled) values. The test is performed using a hypothesis about the mean and standard deviation of the sample for each of the geometric coordinates. The statistical procedure employed is the Chi-square (χ^2) test.. The accuracy of the geometrically corrected image can be estimated separately for the directions *N* and *E*, using standard statistical methodology involving the comparison of a sample value of χ^2 ($\chi^2_{N,n-1}$) and the tabled value ($\chi^2_{n-1,\alpha}$), or ($\chi^2_{E,n-1}$) and ($\chi^2_{n-1,\alpha}$) respectively. The values of $\chi^2_{N,n-1}$ and $\chi^2_{E,n-1}$ are estimated using the following equations:

$$\chi^2_{N,n-1} = (n\text{-}1)\ .\ (\sigma_N^2/\theta_N^2) \tag{3}$$

$$\chi^2_{E,n-1} = (n\text{-}1)\ .\ (\sigma_E^2/\theta_E^2) \tag{4}$$

where θ_N and θ_E are obtained from **Table 1** and vary as a function of map scale using the formulae: $\theta_N = \theta_E = SE/\sqrt{2}$. The values of the *Standard Error* (SE) for the Brazilian Map Accuracy Standards, for instance, is defined by the decree n° 89.817 of 1984, which classifies cartographic products in relation to their geometric quality (see **Table 1**).

Table 1. Standard Error (SE) Values for Brazilian Map Accuracy Standards for the scale 1:100.000 (source Vieira et al., 2002).

CLASSES	**PLANIMETRY**		**SCALE 1:100.000**	
	CAS	**SE**	θ_N	θ_E
A	0.5 mm	0.3 mm	21.2132	21.2132
B	0.8 mm	0.5 mm	35.3553	35.3553
C	1.0 mm	0.6 mm	42.4264	42.4264

3.1.2 Generated Point Method

One drawback of some of the standard approaches to quality control of cartographic products is the difficulty of obtaining homologous points in both representations. It is therefore necessary to consider the use of generic features to complement the control points.

The generated point method can be applied to digitised homologous features (i.e., the same features represented in both map and image) in order to generate a set of equally spaced homologous coordinates following the path of both features.

The initial control points for each features should be homologous, so the relative distances (or deviations *D*) between the generated homologous points are used to perform the comparison. It is evident that if there is no deviation between the generated homologous points, the image is well corrected with reference to the map; otherwise, it is necessary to apply statistical analysis to in order to check the positional accuracy.

A comparison between the median and standard deviation of these deviations and published Map Accuracy Standards (*MAS*) are carried out considering a specific scale. The accuracy test uses a Chi-square (χ^2) test based on the specified Standard Error (SE). The geometrically corrected image will be accepted as accurate if $\chi^2_{D,n-1} < \chi^2_{n-1,\alpha}$. The sample value of $\chi^2_{D,n-1}$ can be estimated using equation (5):

$$\chi^2_{D,n-1} = (n\text{-}1)\ .\ (\sigma_D^2/\theta_D^2) \tag{5}$$

where, as before, θ_D is obtained from the **Table 1**. However, it is not directional, and separate tests are not carried out for the *N* and *E* dimensions separately. The value θ_D is computed from the formula $\theta_D = SE/\sqrt{2}$.

3.2 Thematic Accuracy

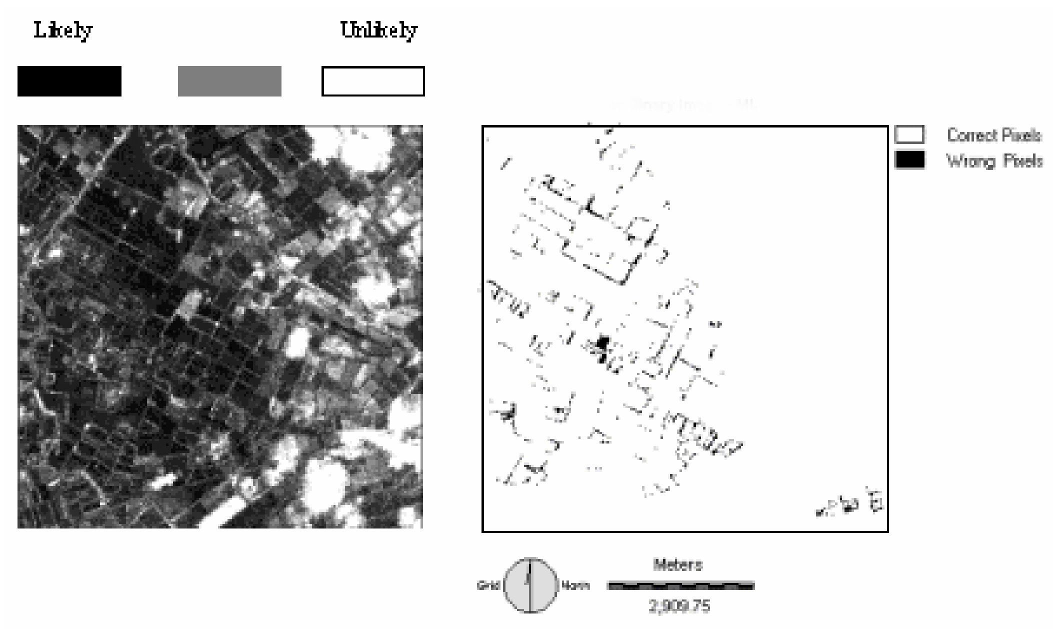
Current accuracy assessment methods are based on non-spatial statistics derived from the confusion or error matrix, which compares the output of a classifier and known test data (**Table 2**). These statistics include overall accuracy, individual class accuracy, user's and producer's accuracy, and several other statistics. Although these measures are in widespread use, none of them considers the spatial distribution of erroneously classified pixels, either implicitly or explicitly.

Table 2. Confusion or error matrix (source Vieira and Mather, 2001).

	Reference Data										
Classes	**1**	**2**	**3**	**4**	**5**	**6**	**TOTAL**	**Users(%)**	**Z**	**K(cond)**	**Variance**
1	344	8	2	1	0	0	355	96.9	87.685	0.963	0.000121
2	33	349	2	2	1	5	392	89	46.767	0.868	0.000345
3	8	21	388	5	5	6	433	89.6	50.784	0.875	0.000297
4	13	20	5	390	0	30	458	85.2	42.546	0.822	0.000373
5	0	1	3	2	394	0	400	98.5	135.018	0.982	0.000053
6	2	1	0	0	0	359	362	99.2	173.393	0.99	0.000033
TOTAL	400	400	400	400	400	400	2400	**OVERALL**	**Z**	**Kappa**	**Variance**
Producers(%)	86	87.3	97	97.5	98.5	89.8		92.70%	142.937	0.912	0.000041

3.2.1 Characterizing the Spatial Distribution of the Errors

One possible way to characterize the spatial distribution of the errors in a thematic classification is by generating a “distance image” (see **Figure 1**(a)) showing the distance from individual pixels to the multivariate means of the classes to which they have been assigned. Either the Euclidean distance or the Mahalanobis distance measure can be used. The former, however, implies spherical clusters in feature space, while the latter takes into account the covariance between the features on which the classification is based. The individual distances are scaled onto a 0-255 range, and displayed as a grey scale image. Darker pixels are spectrally "nearer" to their class centroid (in the sense of statistical distance), and are thus more likely to be classified correctly. On the other hand, pixels with higher distance values are spectrally further from the centroid of the class to which they were assigned, and are thus more likely to be misclassified. A threshold can be applied to the distance image to identify those pixels that are most likely to be misclassified.



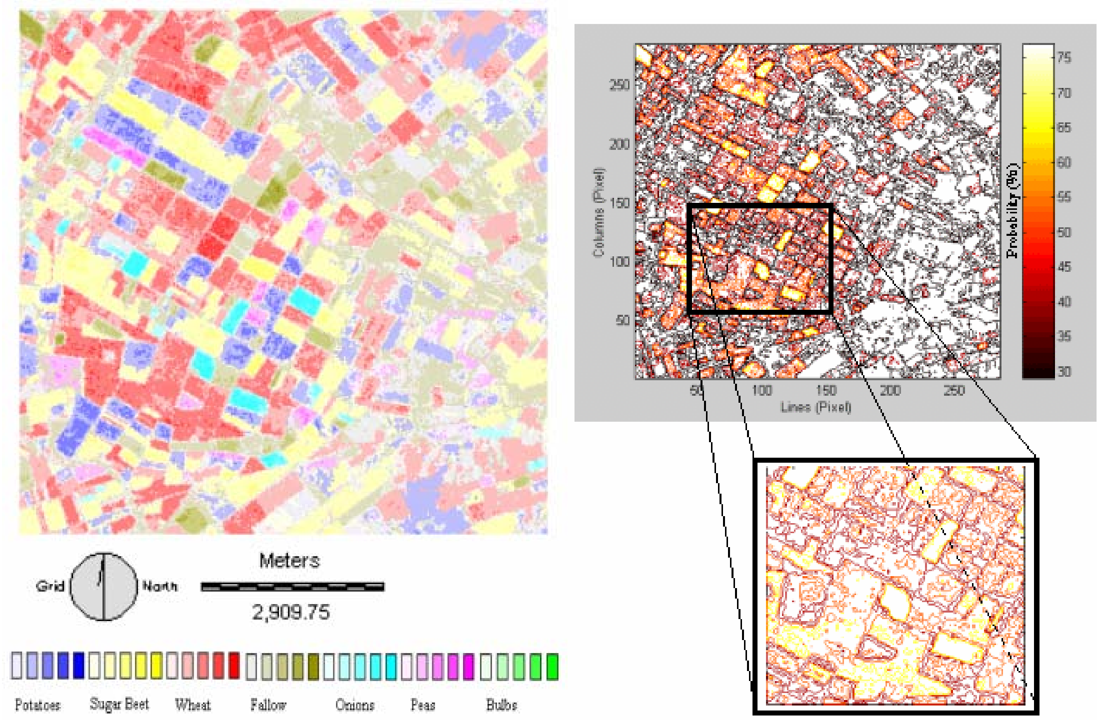
(a) Distance Image (b) Error Image

Figure 1. Spatial characterization of classification errors using thematic image generated by Maximum Likelihood Classifier (385 by 385 pixels).

An alternative way of looking at the spatial distribution of the errors present in a classified image is by directly comparing thematic images with their respective ground truth maps. One of the products of this comparison should be a binary error image (**Figure 1**(b)) in which each point takes the value 0 (correctly labelled) or 1 (erroneously labelled). By examining the spatial distribution of such pixels in **Figure 1** we can make a number of observations. It is apparent that misclassified pixels are spatially correlated. These correlation effects are probably due to the presence of mixed pixels at field boundaries, to variation in the reflectance spectrum caused, most probably, by variations in soil type within a field, or to the effects of crop management practices such as the use of fertilisers. Spatial analysis measures (e.g., Join Count Statistics) could be used in order to determine whether these correlation effects are random or clustered in their spatial distribution. Looking at the spatial distribution of the remaining errors can help to refine the classification process.

3.2.2 Visualizing the Reliability

Any distance measure between the pixel and the mean pixel values (or prototypes) of each class can be used to compute a measure of reliability of a pixel's label. These measures of reliability could be then combined to the already assigned class label in order to generate a new thematic value for the pixel, which not only indicates the class to which the pixels was assigned but also the degree of accuracy achieved. A separate color is assigned to each class. Within-class levels are also assigned separate shades of that color, so that each class is represented by five shades of the given color (see **Figure 2**(a)). This kind of representation allows the visual appreciation of the degree of accuracy of the classified crop. A contour representation of the reliabilities can also be used (**Figure 2**(b)). These types of representation help the user to identify portions of the thematic map that have reduced reliability. Although the final map may look uniform in its accuracy, it is actually a representative assemblage from several image processing procedures and refinements. It is important for the user to known how these accuracies are spatially distributed in the image through a thematic reliability map.



(a) Thematic Reliability (b) Reliability Contour Representation

Figure 2. Representation of the reliabilities using a Maximum Likelihood classifier (385 by 385 pixels).

4. Results and Discussion

A summary of the data used in this study is presented in **Table 3**.

Table 3. Summary of the mean deviation, standard deviations used in the Trend and Accuracy analysis; Generated Point method; and Areal and equivalent Rectangles approach.

Map Accuracy Standards (MAS) Determination					
28 Points Collected.	Image	LANDSAT		CBERS	
	Direction	ΔE	ΔN	ΔE	ΔN
	Mean	3.5146	-1.7826	-10.9780	2.5555
	Stand Deviations	45.9197	48.0931	46.8662	46.9550
	Max. Errors	80.3581	-85.4290'	-94.4135	140.9590
Generated Point Method					
63 Generated Points (Equally spaced)		Distances Between Features (Image-Map)			
	Image	LANDSAT		CBERS	
	Mean	108.3339		76.50388	
	Stand Deviations	30.4817		56.60366	
	Max. Distances	176.8237		237.7162	

4.1 Trend Analysis

Trend analysis was carried out using the *Student's t* distribution and a confidence level of 90% ($\alpha = 0.10$). The critical value obtained from statistical table for 28 control points is: $T_{27\,,\,0.10}$= 1.703. Using the Equations (1) and (2) in order to compute estimated values of t_N and t_E.

LANDSAT:

t_N = 0,1926 < 1,703 and t_E = 0,3977 < 1,703 (there is no trend in these directions)

CBERS:

t_N = 0,2828 < 1,703 and t_E = 1,2172 < 1,703 (there is no trend in these directions)

4.2 Accuracy Analysis

Accuracy analysis was carried out for both Landsat and CBERS images and the results of the estimates of $\chi^2_{N,n-1}$ and $\chi^2_{E,n-1}$, computed using Equation (3) and (4), the first part of **Table 3** and **Table 1**, are presented in **Table 4**.

Table 4. Estimated values of $\chi^2_{N,n-1}$ and $\chi^2_{E,n-1}$ used in the accuracy analysis for the Landsat and CBERS images.

CLASSES	DIRECTIONS	LANDSAT	CBERS
A	**E**	126.5172	131.7865
	N	138.7768	132.2864
B	**E**	45.5463	47.4432
	N	49.9598	47.6232
C	**E**	31.6293	32.9466
	N	34.6942	33.0716

Adopting the critical value of χ^2 = 36,7412 and considering the limit values for the classes A, B, and C as shown in Table 1 for the Brazilian Map Accuracy Standards (scale 1:100.000), these two images have accuracy equivalent to the class C.

4.3 Generated Point Method

The values of the Standard Error (SE) for the generated point method are the same as the Brazilian Map Accuracy Standards, for instance, (see **Table 1**). As this method works with relative distances between homologous points, there is no need to apply trend analysis to check for the presence of systematic errors in the E and N directions.

The accuracy analysis was also performed for both Landsat and CBERS images using a set of equally spaced homologous coordinates in order to check the positional feature accuracy for a given confidence level. The results are presented in **Table 5**.

Table 5. Estimated values of $\chi^2_{D,n-1}$ used in the accuracy analysis for the Landsat and CBERS images.

CLASSES	LANDSAT	CBERS
A	128,0141	441,4366
B	46,0852	158,9175
C	32,0035	110,3592

The critical value of χ^2 is 48,2329 and the limit values are given in **Table 1** for the Brazilian Map Accuracy Standards (scale 1:100.000). The Landsat image has an accuracy equivalent to class B, while the CBERS product does not fit in any specify class.

5. Conclusions

Trend analysis indicates that there is no systematic error in any direction for the Landsat and CBERS geometrically corrected images at the 90% confidence level. On the other hand, both corrected image have an accuracy equivalent to class C using the Brazilian Map Accuracy Standards for a map scale of 1:100.000. Only the Landsat image fits the class B specification, using the generated point method.

These results show that a considerable amount of research needs to be undertaken before the spatial characterization of positional and thematic accuracy associated with remote sensing data can be adequately reported in standardized format and legends. Several techniques for the quality control of spatial databases using generic features are adapted to the context of remote sensing. However, one drawback for some of these approaches is the difficulty in obtaining homologous points in both representations. Alternative techniques for overcoming such limitations could be the use of a spline Fitted method, in which the shape of curves fitted using splines are compared instead of isolated homologous control points (Galo et al., 2001).

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