Impact of Intraband Misregistration on Image Classification

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Abstract

Remote sensing data acquired from spaceborne platforms in multispectral channels with moderate to high spatial resolution has been extensively used for numerous applications. Registration between images as well as multispectral bands significantly affects the classification accuracy. Data acquired in multiple channels needs accurate intraband registration to minimise classification errors. Availability of very high spatial resolution data such as from SPOT, IRS-P6, IKONOS, and Quickbird demands very accurate intraband registration. Ability to provide accurate intraband registration requires proper knowledge of satellite attitude, Earth rotation correction, sensor geometry etc. While every effort is made to minimise the intraband misregistration at product generation level, it is difficult to remove it all together. In view of this and its significance on remote sensing image classification, an attempt was made to evaluate the impact of intraband misregistration on classification of remote sensing image with high spatial resolution data. Study carried using a prototype image and IRS-P6 LISS-IV image reveals that image data with intraband misregistration greater than 20% significantly reduce image sharpness and leads to misclassification. Though misregistration of NIR band has major impact on classification it was also seen that misregistration among all bands would lead to even greater error in classification and increased edge blurring.

1. Introduction

While role of remote sensing technology as information provider is well established, usefulness of data collected by remote sensors is dependent on numerous qualities of sensor systems. Several studies have been reported in the literature on effect of image misregistration on the accuracy of remotely sensed change detection (Dai and Khorram, 1998, Townshend et al., 1992). If accurate registration between images acquired at different times by the same sensor or by different sensors is not achieved, then spurious differences will be detected, which arise due to comparison of different locations and not because of differences in properties at the same location between one time and another. Similarly, the multispectral band-to-band misalignment is a key factor in remote sensing and a mismatch between the various spectral bands inevitably leads to decreased accuracy for every application that makes explicit use of the spectral information (Bretschneider, 2002). Improvements in sensor technology and imaging techniques in recent years have led to availability of high spatial and spectral resolution multi-spectral remote sensing data from several spaceborne sensors. To name a few, IKONOS and IRS-P6 satellites provide data

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at 4m and 5.6m spatial resolution in 4 and 3 multi-spectral bands respectively. Similarly, the Hyperion onboard the EO-1 satellite is the first spaceborne hyperspectral sensor covering the complete spectral range from 0.4 to 2.5 μm in 220 bands with a spatial resolution of 30m. For such high resolution data and their subsequent interpretation a high level accuracy in intraband registration is required. The usefulness of high resolution data will be realised only if registration is achieved to subpixel level.

For a pushbroom type of sensor onboard SPOT, IKONOS and IRS-P6 mentioned above, sources of error in band to band registration arise due to (i) uncertainty in satellite attitude determination and attitude rate, and (ii) Earth rotation during the time elapsed between observations of the same ground area by three successive arrays of detectors, corresponding to different spectral bands. The causes for the displacement are mainly determined by the design of the actual acquisition unit, i.e. the arrangement of the charge coupled devices (CCD). Two different kinds of discontinuities have to be considered: Firstly the inter-band displacement, which results from the imperfect mounting of the individual scan lines, effects the bands to be globally shifted - and possible slightly rotated - with respect to each other. Secondly the creation of a virtual scan line by using a number of CCDs with the aim to gain a larger swath yields in intraband discontinuities. Even for professional satellites like SPOT the shift between corresponding pixel centres can mount to 2/3 of a pixel, which is equivalent to approximately 13m on the ground (Bretschneider et al., 2001). The resulting pro- blems from displaced bands are manifold for the subsequently used applications. One example is given by degraded classification accuracy since the pixels exhibit a high degree of mixed spectral classes due to the spatial differences between the observations in each band.

Usability of multispectral imagery for applications that depend on spectral information content are affected by any spatial offset between spectral bands. For any multispectral remote sensing satellite data, band-to-band registration is a mandatory requirement with high accuracy. It becomes all the more important and critical for high spatial resolution data available from several platforms these days. Any band to band misregistration beyond acceptable limits would lead to errors in data analysis and interpretation in terms of land resources information as it leads to image blurring, and signature impurity. As mentioned by Billingsley (1982) alignment between the bands has to be better than 0.1 - 0.2 pixel for precise classification. With spatial resolution of multispectral remote sensing sensors attaining sub meter level in recent years, realizing such alignment precision across the bands would be highly demanding.

While every effort is put to remove intraband misregistration errors during data product generation, it is difficult to rule out misregistration completely at sub pixel level. It is worthwhile to note, for example, the SPOT specification only guarantees that the centers of three corresponding pixels in the different bands fall within a circle with a radius up to a third of a pixel (SPOT Image 1988). Evaluation of impact of intraband misregistration at sub pixel level on image classification makes an interesting and significant study. One such attempt was carried out with the data acquired by the IRS-P6 LISS-IV in the present study by deliberately introducing intraband misregistration.

IRS series of satellites with Linear Imaging Self Scanning (LISS) and wide Field Sensor (WiFS) cameras are one of the major sources of remote sensing data for resources identification and inventorying (IRS-P6 Handbook, 2004). Resourcesat-1 (IRS-P6) is the latest in the IRS series of satellites launched on October 17, 2003. IRS-P6 is a continuation of IRS-1C/1D series of satellites with enhanced capabilities. It has three sensors on board, a multispectral LISS-III, AWiFS and a high resolution LISS-IV camera.

LISS-IV is a three band pushbroom camera which uses refractive optics in 3 spectral bands (with separate optics and detector array for each band) with a spatial resolution of 5.6m and a swath of 23 km in multispectral mode and 70 km in single band MONO mode. In addition, LISS-IV camera has tilting capability for stereo coverage in multispectral or mono mode.

The three detector arrays of LISS-IV, corresponding to the three bands are physically separated in the camera such that imaging time interval between the extreme set of arrays being 2.1 seconds, which approximately corresponds to 13 km on the ground. In addition, in each of the bands, the odd and even pixels are staggered by about five lines in the focal plane. It implies that, the ground is imaged first by one set of detectors and the Earth rotates by some amount before the second set of detectors image the same ground area (Gurjar et .al., 2002). This arrangement of detector arrays needs some processing for relative motion between the Earth and satellite, which is achieved by yaw steering. However, any error in attitude or attitude rate (which varies within a scene) determination would lead to intraband misregistration. In case of LISS-IV camera of IRS-P6, the subpixel level registration is achieved by area-correlation with least square surface fitting method. This method takes care of the misregistration due to yaw between arrays as long as the inter array yaw is less than 3° (Gurjar et al., 2002).

2. Objectives

Band to band misregistration in remote sensing data affects the results of image classification. Misregistration among various bands of multispectral data can cause loss of image sharpness, as well as misclassification of pixels, which could be prominently seen along the class boundaries. The present study was taken up with the following objectives:

1. To evaluate the impact of band to band misregistration of high resolution multispectral data in terms of edge sharpness
2. To study the impact of band to band misregistration on the accuracy of remote sensing data classification in quantitative terms.

3. Methodology

To address the influence of intraband misregistration at pixel level, it is important to use a data set that is known to have no source of errors leading to misclassification, either due to overlapping class statistics (or signatures) or mixed pixels or blurred edges. In addition, it is also important to have a *priori* knowledge of extent of various classes present in the image.

To meet these requirements and to validate the adopted evaluation criteria (discussed in the following sections), procedure adopted comprises (i) generating a synthetic image with pure classes as one would see in a multispectral remote sensing image, (ii) clear class boundaries in different shapes and (iii) testing the evaluation criteria adopted in the study for its applicability. The other data set comprises part of IRS-P6 LISS-IV image acquired over an area with several land use and land covers and known ground information.

3.1 Synthetic (Test) data set

A synthetic image of (256 pixels x 256 lines) with 7 classes representing shallow and deep water, plantation, forest, tobacco crop, red soil and sand was generated with mean and standard deviation as observed with LISS-III data set. Care was taken in selecting these classes such that all classes are distinct and clearly separable as it was necessary to minimise classification errors due to overlapping class signatures. In addition, location and number of pixels belonging to each of these classes is exactly known to aid in computation of mapping and classification accuracy. The test image is characterised with linear (vertical, horizontal and diagonal) and curvilinear edges. With a data set of this kind, it is possible to attribute any classification errors in a data set entirely to the induced band-to-band misregistration. Figure 4 shows the synthetic image used in the study and statistics of each of classes are shown in table 1.

3.2 Remote sensing data set

Real world remote sensing data set used in the study was acquired by IRS-P6 LISS-IV on 29 February 2004 and the intraband misregistration of the image supplied by NDC, NRSA is negligible (less than 20% of a pixel) and within quality specifications of the product. A part of the image consisting of (1024 pixels x 1024 lines) was extracted for the present study. It covers parts of Guntur and Krishna districts in Andhra Pradesh and is characterised by multiple crops, river Krishna and irrigation canals, fallow lands and built up areas. In all 14 classes were identified in the area covered by the sub image.

3.3 Simulation of band-to-band misregistration

Figure 1 shows schematic diagram of the procedure followed in the study. Intraband misregistration has been induced into the test and LISS-IV images at sub pixel level by (i) resampling the original pixel to one fifth of the original size (i.e., 1m in case of 5m LISS-IV data set) by nearest neighbour technique, (ii) displacing one or two bands relative to band 2 such that different levels of misregistration is realised as shown in Figure 2 and (iii) resampling by pixel aggregation to original pixel size of 5m (in case of LISS-IV) data. During the initial step, resampling of original data at 5m pixel size to 1m pixel size

Table 1 : Class statistics used in synthetic image generation based on their representation in LISS-III image

Class Name	Lable	No. of Pixels	Band	Min	Max	Mean	Standard Deviation.
Deep Water	5	8127	Green	71	76	73.25	0.91
			Red	30	34	31.95	0.58
			NIR	12	18	14.91	0.96
Shallow Water	7	8192	Green	106	113	109.54	0.96
			Red	47	50	48.17	0.54
			NIR	16	20	18.11	0.76
Red Soil	3	8130	Green	87	106	97.73	2.94
			Red	63	93	79.36	4.64
			NIR	68	90	79.88	3.36
Plantation	2	11715	Green	74	82	78.19	1.27
			Red	33	40	36.60	1.07
			NIR	81	96	88.93	2.49
Forest	4	8257	Green	64	75	68.99	1.64
			Red	33	40	36.55	1.08
			NIR	84	113	97.35	4.30
Crop	1	12923	Green	87	101	93.77	2.31
			Red	33	41	37.14	1.38
			NIR	145	204	172.69	9.65
River Sand	6	8192	Green	125	201	162.16	12.28
			Red	90	168	128.16	12.59
			NIR	73	143	107.60	11.24

was carried out using Nearest Neighbour (NN) resampling to retain the original grey values. On the other hand, aggregation (average of 5x5 pixels of 1m size to realise 5m pixel) of pixel values was carried out to account for the change in grey level due to sub-pixel misregistration of the band under consideration.

Figure 2 shows the five cases of band-to-band sub pixel misregistration simulated in the present study. For all 5 cases, band-2 is undisturbed and used as reference band. Thus, Case-A shows misregistration of 20% in one dimension of band-4 relative to both bands 2 & 3. Similarly, Case-B shows displacement of bands 3 & 4 relative to band 2 causing an overall misregistration of 40%. In this case, band 4 is misregistered to the left by 20% while band 3 is misregistered to the right of corresponding pixel in band 2 by 20%. Two-dimensional misregistration of band-4 relative to the other 2 bands by 36%, 52% and 64% was generated as shown in Cases C, D & E, respectively.

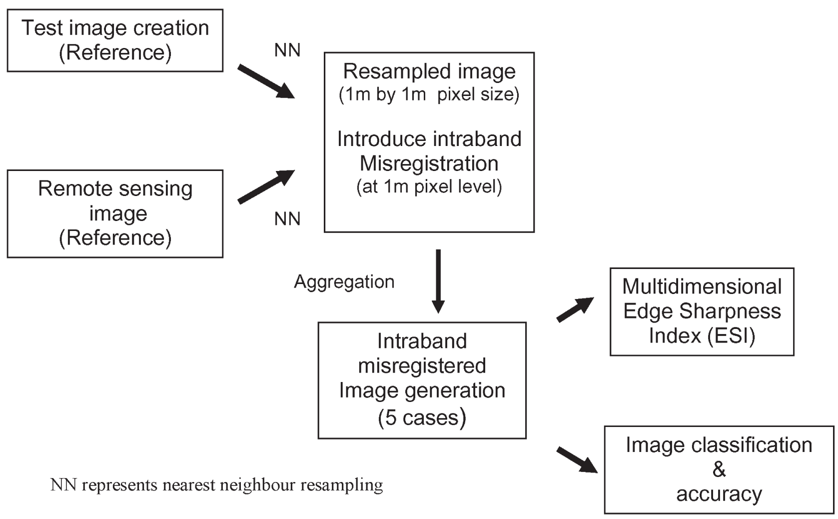

Figure 1 : Schematic diagram of procedure followed in the study

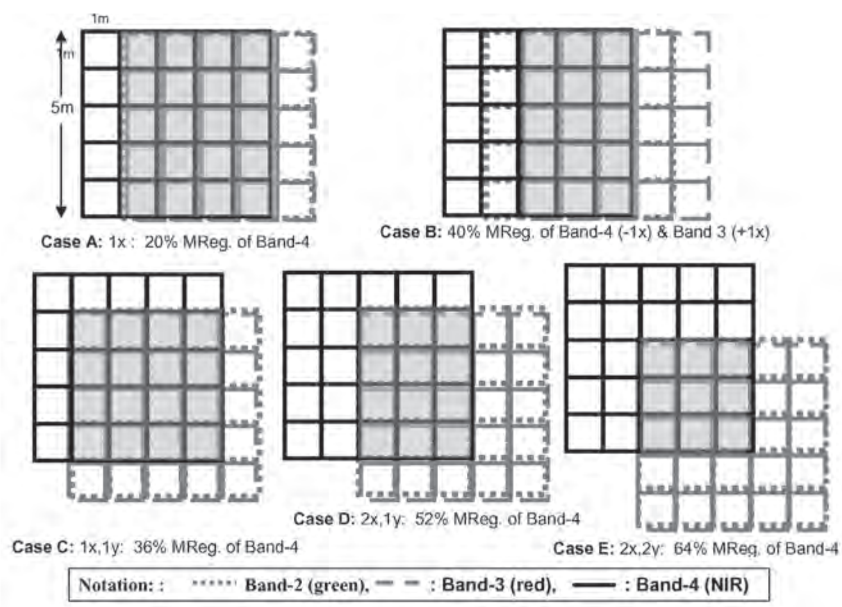

Figure 2 : Five types of intraband misregistration, ranging from 20% to 64% at subpixel level, used in the study

3.4 Evaluation criteria

To investigate the above objectives, the evaluation criteria adopted was based on determination of

- Edge blurring
- Edge displacement
- Classification accuracy

Edge blurring: On a three channel multispectral data set, to arrive at the magnitude of edge blurring, Edge Sharpness Index (adopted from Edge Strength Index, which is unidimensional as defined by Narasimharao et al, 1994) has been computed taking into consideration of difference in grey level values of pixels across an edge in all bands as defined below. ESI essentially defines the change in edge sharpness (increased or decreased) relative to the reference image and percent edge blurring is then computed as (1-ESI)*100.0

Edge Sharpness Index (ESI) :

$$ESI = \frac{\sum\sum_{i=1,nb;\, j=1,N} (DN_{i,J} - DN_{i+1,J})^2_{Misregistered}}{\sum\sum_{i=1,nb;\, j=1,N} (DN_{i,J} - DN_{i+1,J})^2_{Reference}} \quad \text{Equation 1}$$

Edge displacement: Edges were computed for classified images of the data used in the study. The edge migration due to blurring of edges as a result of band-to-band misregistration was determined in terms of number of pixels and misalignment of edge.

Image classification: The images used in the study were classified using Maximum Likelihood (ML) classification algorithm with known classes by defining the training areas and computing the statistics. The impact of intraband misregistration on classification result was computed in terms of (i) number of pixels (or area) classified into each of the classes for all 5 cases of intraband misregistration and compared with that of reference image to arrive at the overall accuracy and (ii) agreement in class label at every pixel level to account for mapping accuracy as well. In addition, kappa coefficient was computed for all cases as it is widely known to represent the classification accuracy.

4. Results and Discussion

Results of the study are presented in this section for both the data sets following the criteria mentioned in Sec. 3.3. Figure 3 shows the impact of intraband misregistration on blurring of edges across the class boundaries for the synthetic and LISS-IV images. The percent edge blurring was computed using ESI for a good number of edge pixels interactively selected from the resultant images. Observed reduction in edge sharpness for test image is minimum for Case A misregistration (8.82%) while it is maximum for Case B (32.92%) followed by Case E (28.43%). Higher reduction in edge sharpness in Case B is due to the induced misregistration of bands 3 (red band) and 4 (NIR band) by 0.2 pixels to band 2 (Green band). While these values are valid for images with predominantly homogeneous areas and sharp boundaries, the blurring of edges could exponentially increase for more heterogeneous and highly textured regions and thin edges. Similar trends, though of lesser magnitude, of edge blurring have been observed with remote sensing image also (Figure 3(b)).

Figure 4 shows the test and Case E input images and their classification along with the class boundaries derived from the classified outputs. It is clear from these figures that misclassification of pixels, is seen at the edges with edge displacement across pair of classes, namely forest and deep water, sand and deep water, red soil and forest. From the illustration, it is clear that the edge sharpness is reduced due to misregistration leading to broadened boundaries between the classes. In addition, the illustration shows, intraband misregistration has no significant impact on classification of pixels lying within the class regions for clearly separable classes considered in the test image.

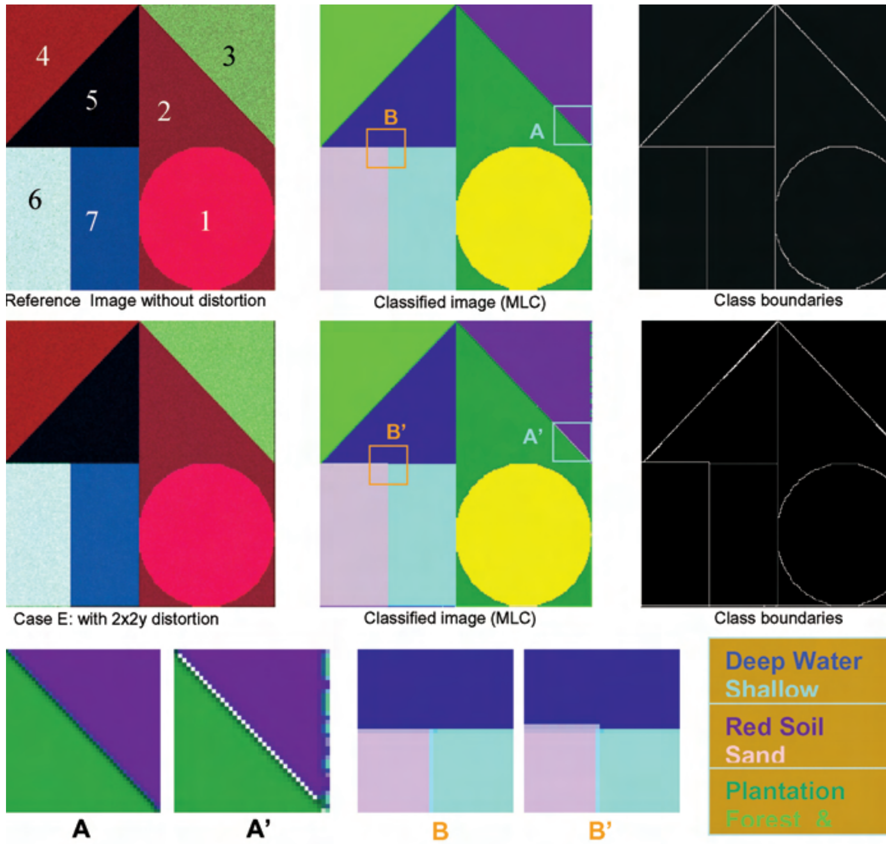

Figure 4 : Original synthetic image of size (256x256), Case E FCC and Classified images of test data along with the class boundaries; A, A' and B,B' highlighting the misclassification and displaced edges

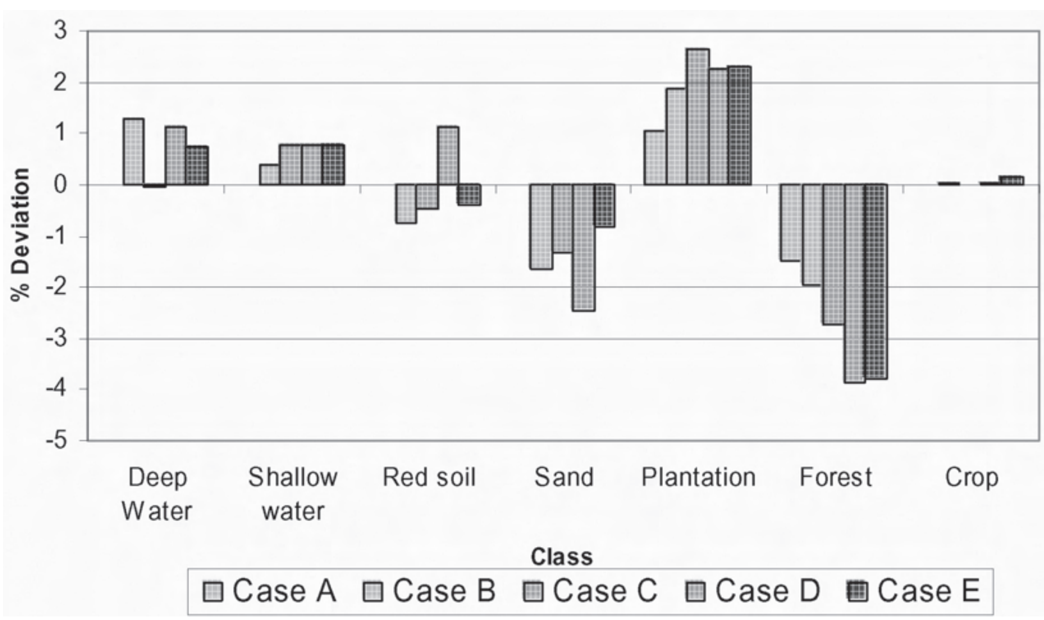

Figure 5 : Percent deviation of extent of each of the classes for all 5 cases of Intraband misregistration relative to test image

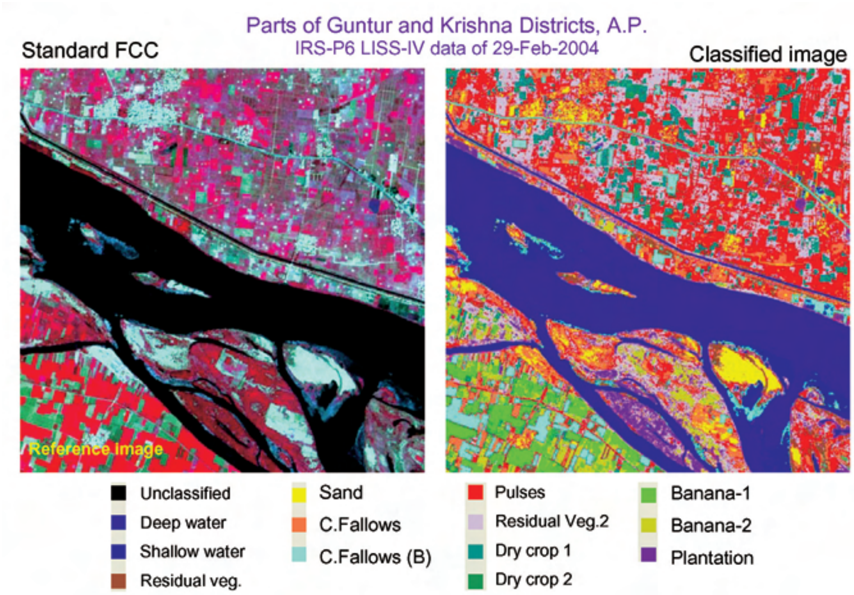

Figure 6 : Standard FCC of IRS-P6 LISS-IV and its classified image of parts of Guntur, A.P., India

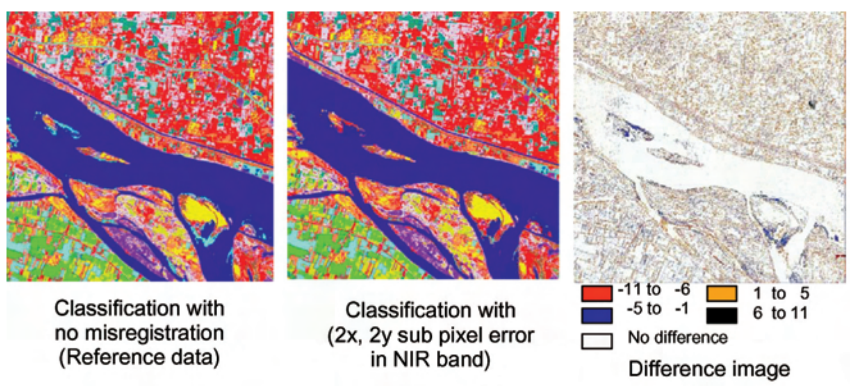

Figure 7 : Illustration of impact of intraband misregistration (Case E) on Mapping accuracy

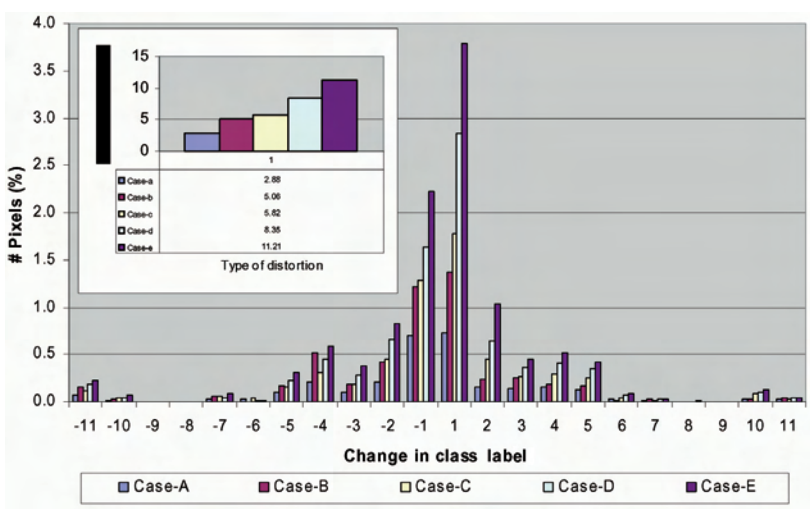

Figure 8 : Impact of intraband misregistration on classification accuracy and Resulting changes in class label

Similarly, Figure 5 shows percent deviation of area estimation under each of the classes for all 5 cases of intraband misregistration. Observed percent deviation is maximum for forest class followed by plantation. However, it is interesting to note that a class like crop with distinct class signature and far from rest of the classes in the spectral space is least affected by the intraband misregistration.

Figure 6 shows the standard FCC of LISS-IV image with no intraband misregistration and its classified image with 14 classes. Effect of intra-band misregistration for remote sensing image has been illustrated in Figures 7 and 8 taking Case E misregistration as an example. It is obvious from the difference image shown in Figure 7 that misclassification of land use land cover categories is fairly large with significant changes in class labels for several classes. A pictorial representation, in terms of percent of pixels with changed class lable is shown in Figure 8. Figure 8 also shows the percent of misclassification for all cases of misregistration, which increased with increased error in intraband misregistration.

Finally, Table 2 shows estimated Kappa accuracy for all cases of intraband misregistration of test as well as remote sensing data sets used in the study. As seen from the table, Kappa decreased with increased misregistration from 0.99 to 0.96 respectively for Case A & E for test image. However, the fact that it is not consistent could be seen with Kappa result in the case of remote sensing image used in the study, which needs further investigation. One plausible explanation could be inadequacy of Kappa coefficient to account for commission and omission errors, which could be shown clearly in Figure7 with a pixel by pixel comparison in the form of difference image.

5. Conclusions

Remote sensing data acquired by several modern sensors in multispectral bands, ranging from a few to a few hundred requires accurate

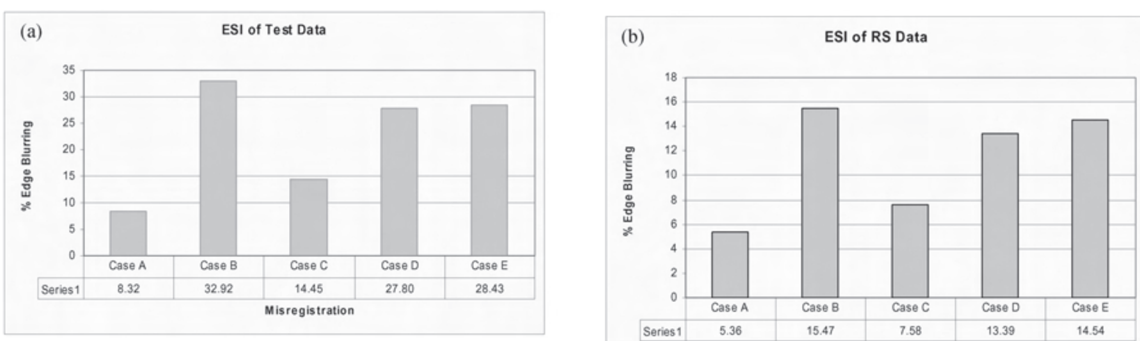

Figure 3. : IIIustration of reduction in edge sharpness for (a) test image and (b) LISS-IV image

Table 2 : Kappa coefficient for test and LISS-IV images

Intraband misregistration		Test Data	RS Data
Case A	20%	0.9936	0.7550
Case B	40%	0.9693	0.7636
Case C	36%	0.9911	0.7103
Case D	52%	0.9663	0.6483
Case E	64%	0.9613	0.8701

intraband registration. Intraband misregistration could lead to reduced image sharpness, and overlapping class signatures. An attempt has been made in the present study to evaluate the impact of any intraband misregistration at sub pixel level on image classification and edge sharpness. It was seen that a 20% misregistration of one of three bands leads less than 3% misclassification, in general. However, it is significant at higher levels of misregistration leading to 15% reduced edge sharpness and misclassification to the extent of 11%. Though misregistration of NIR band has major impact on classification it was also seen that misregistration among all bands would lead to even greater error in classification and increased edge blurring. It could, however, be concluded that the impact of intraband misregistration could be even more significant for a scene with considerable heterogeneity due to multiple classes and textured regions and increases with increasing spatial resolution as number of edges increase.

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