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Initial Evaluation of Fused Satellite Images Aplicability to Vectorisation and Classification**

1. Satellite Data Fusion

The simultaneous use of satellite images obtained from various sensors provides complementary information. One of the method of using it in analysis is the application of integration techniques. The spatial resolution of presently available satellite remote sensors varies between several centimetres and a kilometre. Panchromatic satellite images have higher resolution than multispectral ones. Merging of these images allows obtaining new synthetic multispectral data of higher spatial resolution than the original one (Fig. 1).

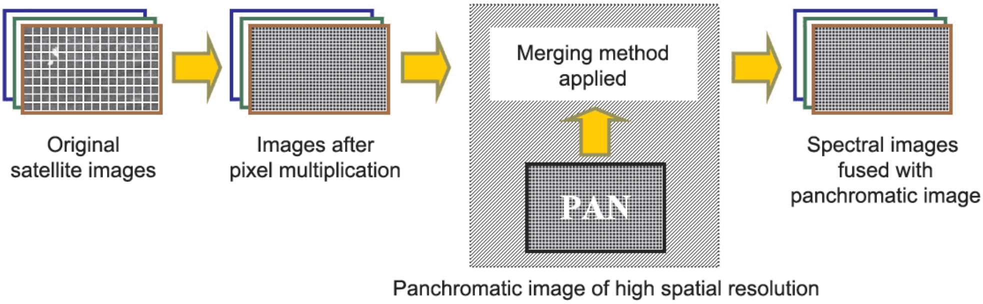

Fig. 1. Merging of images of various resolution

Urban areas are the most difficult for remote sensing survey. There appear small objects of completely different spectral characteristics. Remotely sensed data rich in spatial information is necessary to monitor them. On the other hand, spectral information is needed for detection and differentiation of the urban greenery. High-resolution satellite images provide such data, however obtaining them is

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costly and the spectral data is limited to four bands (IKONOS, QuickBird, EROS, IRS PAN 1C/D). This fact influences interpretation and classification of the data. But, relatively cheap multispectral Landsat TM (30 m), ASTER (15 m, 30 m) and SPOT XS (10 m, 20 m) images provide resolution too low for this kind of survey.

Multispectral data of middle-resolution used along with high-resolution panchromatic data can provide solution to this problem. Proper integration of such data is the key aspect here. Various methods of remotely sensed data integration have been suggested so far [2, 7, 12, 17, 19]. They are focused on data obtained from various sensors and include integration at the level of a pixel. None of the methods has weighty and convincing evidence supporting their superiority over the rest and importance in case of photo interpretation and classification [11, 12, 15, 16]. IHS transformation, despite its limitations and weak points, is the most popular method [3, 8, 13, 15].

Positive results of survey on complementary use of data obtained from different sensors applied in urban studies have been presented by Gamba [5]. Photo interpretation value of multispectral images increase through fusion [3, 7, 15]. However, spectral classification of fused images gives confusing results. Positive findings for urban areas have been obtained by Couloigner *et al.* [4], Raptis *et al.* [18], Vaughan and Oune [24].

For practical reasons it is reasonable to analyse the integration of middle--resolution satellite images for the accuracy of mapping, both thematic and geometric. A few questions arise about the accuracy of the results of photo interpretation and of automatic classification. There are also questions about the influence of the chosen integration method on the results. Due to this, there are two objectives of the presents study. The first one is to define the applicability of merged data to detect different objects through visual interpretation. The next step is to provide a rank list of integration methods.

2. Testing Integration Model

2.1. IHS Method

IHS method is the most widely used technique of merging images. The IHS model describes colours by their intensity (I), hue (H) and saturation (S). The integration procedure in this case is to transform RGB colours to the IHS form and back again. The spatial information is concentrated in the I parameter and the thematic information in parameters H and S [3]. The normalised panchromatic image is used instead of the I parameter and then a reverse procedure takes place. In the present tests the normalisation was done using histogram matching procedure.

2.2. Wiemker's (WMK) Method

In this method the pixel value is weighted by a parameter which equals the ratio of the pixel value in panchromatic band to the sum of pixel values of the bands which the given composite image is formed of [23].

2.3. HPF Method

In the HPF method a high-pass filter is used for the panchromatic image. It removes most of the spectral information and leaves mainly high-frequency spatial information [3, 19]. In the present study a panchromatic image was applied 9×9 high-pass filter. The obtained image was normalised using histogram matching procedure and then added to each spectral band.

2.4. LCM Method

The assumption of this method is that the similar location of edges causes local correlation between the bands, provided that the computation area is small enough. Such local correlation should also be observed when there does not exist global correlation between the images [7]. The local correlation can be described by the local analysis of regression. To apply these correlations in image merging, there is necessary the assumption that the local correlation between the spectral image and the panchromatic image resampled to lower resolution is the same as for the original panchromatic image. The obtained parameters can be applied to the proper area within the high-resolution panchromatic image. LCM integration window of the size 61×61 pixels was used in the study.

3. Data and Survey Area

The set of images used in the study comprised of six LANDSAT 7 ETM+ spectral bands of 30m-resolution and 5.8m-resolution IRS panchromatic image. They were taken on 7 and 21 May 2000 respectively. The integration procedure was applied to 'A' testing field (30 km × 15 km) with the city centre of Cracow in the middle of it (Fig. 2).

Photo interpretation (object recognition and outlining) was done on 5 testing fields 'B1–B5' (1 km × 1 km). Ten objects of different types were chosen within these testing fields (Fig. 3).

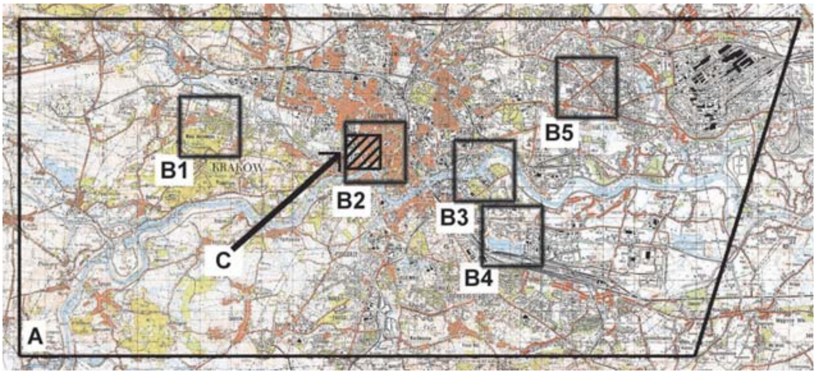

Fig. 2. Landsat and IRS images and testing fields

Classification procedure and the assessment of its accuracy were done on testing field 'C'. Within this square of 500 m × 500 m there are presented various objects (Fig. 3).

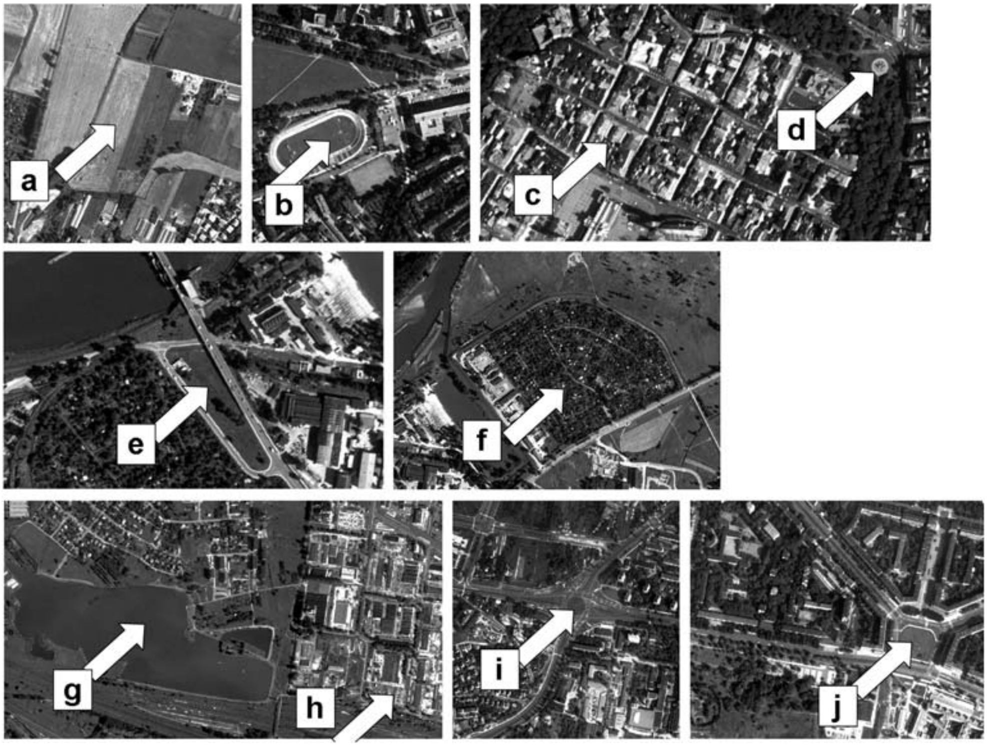

Fig. 3. Testing objects: a) farm field; b) stadium; c) block of buildings; d) asphalt surface; e) greenery area; f) allotment gardens; g) water reservoir; h) industrial building; i) roundabouts; j) town square

4. Survey Objective and Methods Applied

The present study was based on repeated vectorisation of selected objects on different images (original satellite images, images merged with the panchromatic image obtained through different integration techniques). Four methods of integration were used. Ten objects were vectorised on three different colour composite images (Fig. 3). The results were rasterised to 5 m pixel resolution. During the next stage the results were compared with the reference. The reference image was obtained through the same procedure (vectorisation, rasterisation) but the base material was an orthophotomap made from aerial images of scale 1:26 000 and of 1 m pixel size.

The second aim of the study was to assess the applicability of the merged images to spectral classification. This aim was achieved when a referential land cover/land use map (obtained through vectorisation of the airborne orthophotomap) was compared with the results of supervised classification of various satellite images (before and after integration).

In both tests (accuracy of vectorisation and classification), the parameters like producer's accuracy, customer's accuracy and total accuracy were taken into consideration [10].

5. Vectorisation of Original and Fused Images

Ten objects were selected during the first stage of the study (Fig. 3). Each of them was vectorised on a colour orthophotomap based on aerial images of scale 1:26000. In the next stage vectorisation was done on colour composites (CC) formed of Landsat TM spectral bands – the original ones of 30m-resolution and after merging of 5m-resolution. Five sets of images were compared. Vectorisation was done on three colour composite images: in natural colours (CC 123), in false colours with the use of two bands from visible spectral range and near infrared band 4 (CC 134) and blue band and two middle infrared bands (CC157). The CC 134 was chosen, because it received better Optimum Index Factor (OIF) results than the similar standard false colour composite (FCC-CC234). OIF value can be seen as a formal measure of the information potential [2].

The reason for testing more than only one colour composite was twofold. One was to decide if the choice of colour composite can influence the accuracy of the results and, if the infrared bands availability in case of Landsat images, increase the applicability of the material to object outlining.

The key moment of the analysis was to compare the results of vectorisation of the satellite images with the reference obtained from the airborne orthophotomap. To complete this task the vectorised object outlines were rasterised with 5 m resolution. This allowed the comparison of object outlining results on the satellite images before and after integration. To analyse the differences between feature borders on satellite images and on the orthophotomap, the resolution should be 1 metre, but such analysis is out of scope of the present study.

Table 1 presents the consumer's accuracy values obtained for all tested techniques. They can be interpreted as the measure of reliability that a pixel lies within the object. The values in table 2 present producer's accuracy. The results inform how correctly the pixels were classified in each class. There are mean values for each object, for each set of images and for all colour composites. Maximum and minimum values for each object have also been shown here.

Figure 4 shows the values of total accuracy which equals the ratio of properly classified pixels to all the pixels of the tested objects. The chart presents results for all integration techniques and colour composites.

Table 1. Consumer's accuracy for vectorisation of the original Landsat TM images and images fused with the use of four integration methods

	CC	Farm field	Stadium	Block of buildings	Asphalt surface	Greenery area	Allotment gardens	Water reservoir	Industrial building	Roundabouts	Town square
TM	123	0.6025	0.7285	0.8885	0.3448	0.9861	0.9479	0.8246	0.7317	0.7559	0.7924
	134	0.9143	0.7647	0.7027	0.1724	0.9563	0.9194	0.8703	0.7212	1.0000	0.7246
	157	0.8613	0.9163	0.3446	0.0345	0.9980	0.9626	0.8577	0.7491	0.8425	0.5974
IHS	123	0.921	0.9321	0.8851	0.8621	0.9145	0.9824	0.9935	0.9338	0.8346	0.9153
	134	0.9538	0.9593	0.8649	0.9655	0.8907	0.9804	0.9786	0.885	0.9134	0.8178
	157	0.8975	0.8982	0.8649	0.8621	0.8907	0.9936	0.9875	0.9268	0.7559	0.9068
WMK	123	0.9513	0.8846	0.9189	0.8621	0.8907	0.9794	0.9786	0.8955	0.7244	0.8898
	134	0.9849	0.8642	0.8885	0.8621	0.8946	0.9815	0.9737	0.8955	0.8898	0.8856
	157	0.9941	0.9502	0.8750	0.6552	0.9066	0.9915	0.9642	0.9164	0.8740	0.8686
HPF	123	0.9395	0.9140	0.8682	0.9655	0.9105	0.9957	0.9659	0.8397	0.9449	0.9703
	134	0.9168	0.9683	0.8818	1.0000	0.8926	0.9265	0.9444	0.878	0.9843	0.9534
	157	0.8748	0.9661	0.8784	0.9990	0.8946	0.9785	0.9181	0.8467	0.9764	0.9534
LCM	123	0.9008	0.9185	0.8007	0.8621	0.7574	0.9603	0.9746	0.9512	0.7244	0.8686
	134	0.9126	0.8371	0.8513	0.7586	0.8708	0.9582	0.9637	0.9164	0.8819	0.8432
	157	0.8832	0.9706	0.8243	0.7931	0.837	0.972	0.9442	0.9059	0.8346	0.9322
Mean value		0.9006	0.8982	0.8225	0.7332	0.8994	0.9687	0.94264	0.8662	0.8624	0.8612
Min		0.6025	0.7285	0.3446	0.0345	0.7574	0.9194	0.8246	0.7212	0.7244	0.5974
Max		0.9941	0.9706	0.9189	1.0000	0.9980	0.9957	0.9935	0.9512	1.0000	0.9703

Table 2. Producer's accuracy for vectorisation of the original Landsat TM images and images fused with the use of four integration methods

	CC	Farm field	Stadium	Block of buildings	Asphalt surface	Greenery area	Allotment gardens	Water reservoir	Industrial building	Roundabouts	Town square
TM	123	0.7213	0.5600	0.6478	0.2273	0.5071	0.4771	0.9955	0.3665	0.5783	0.5238
	134	0.9135	0.9713	0.8490	0.1219	0.5245	0.9876	0.9876	0.6592	0.4866	0.7844
	157	0.7909	0.8473	0.3054	0.0400	0.3585	0.9360	0.9934	0.8532	0.6993	0.6779
IHS	123	0.8889	0.9928	0.8590	0.8333	0.9787	0.9649	0.9604	0.8590	0.9815	0.7397
	134	0.9570	0.9883	0.8505	0.9333	0.9392	0.9721	0.9704	0.8728	0.9280	0.9554
	157	0.9561	1.0000	0.8421	0.9259	0.9432	0.9627	0.9709	0.9078	0.9697	0.9640
WMK	123	0.9137	1.0000	0.8447	0.9615	0.9295	0.9640	0.9856	0.8986	1.0000	0.8898
	134	0.9071	0.9922	0.8595	1.0000	0.9240	0.9634	0.9807	0.9278	0.9826	0.9248
	157	0.9114	0.9655	0.8436	1.0000	0.9249	0.9675	0.9835	0.8855	0.8538	0.9276
HPF	123	0.9458	0.9951	0.8771	0.9333	0.9765	0.9646	0.9830	0.8732	0.9917	0.8876
	134	0.9191	0.9772	0.8156	0.8056	0.9656	0.9723	0.9789	0.8571	0.9470	0.8858
	157	0.9849	0.9574	0.8254	0.8788	0.9868	0.9635	0.9864	0.9643	0.9394	0.8272
LCM	123	0.8631	0.9975	0.8650	0.6944	0.9769	0.9817	0.9665	0.8452	0.5750	0.8991
	134	0.8631	0.9975	0.8650	0.6944	0.9769	0.9817	0.9665	0.8452	0.5750	0.8991
	157	0.7627	0.9662	0.8299	0.7667	0.9768	0.9811	0.9857	0.9286	0.4491	0.7586
Mean value		0.8866	0.9472	0.7986	0.7211	0.8593	0.9360	0.9797	0.8363	0.7971	0.8363
Min		0.7213	0.5600	0.3054	0.0400	0.3585	0.4771	0.9604	0.3665	0.4491	0.5238
Max		0.9849	1.0000	0.8771	1.0000	0.9868	0.9876	0.9955	0.9643	1.0000	0.9640

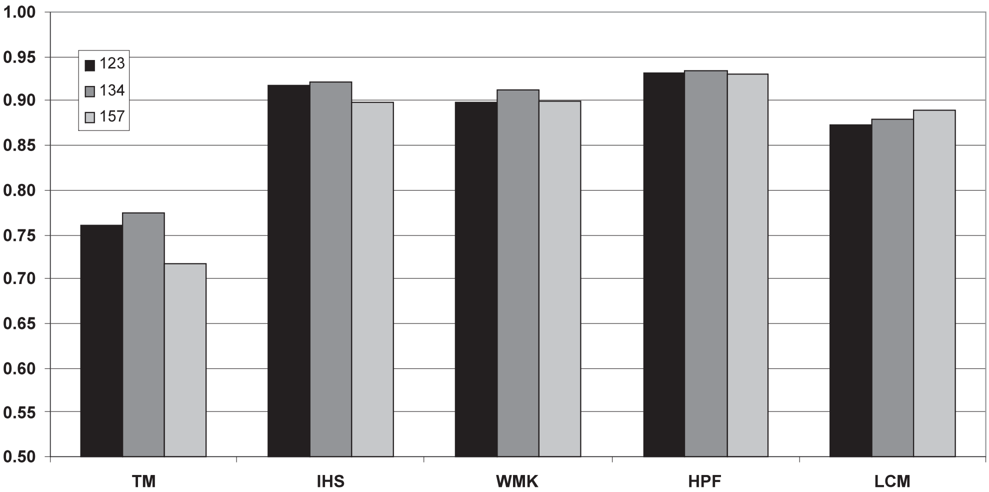

Fig. 4. Total accuracy obtained for the tested objects

6. Supervised Classification of Original and Merged Satellite Images

In the present study there was tested the applicability of fused spectral bands for maximum likelihood supervised classification. Limiting the testing field to a 500 m × 500 m square allowed preparing detailed reference land use/land cover map. Orthophotomap based on PHARE aerial images (Fig. 5a) was used, vectorised and verified in the terrain. After the initial classification of multispectral images the reference land use/land cover map was generalised to four categories (Fig. 5b). This was done due to the relatively big pixel sizes (30 m and 5 m), which fact becomes an obstacle in the urban areas to precede classification with a bigger number of categories.

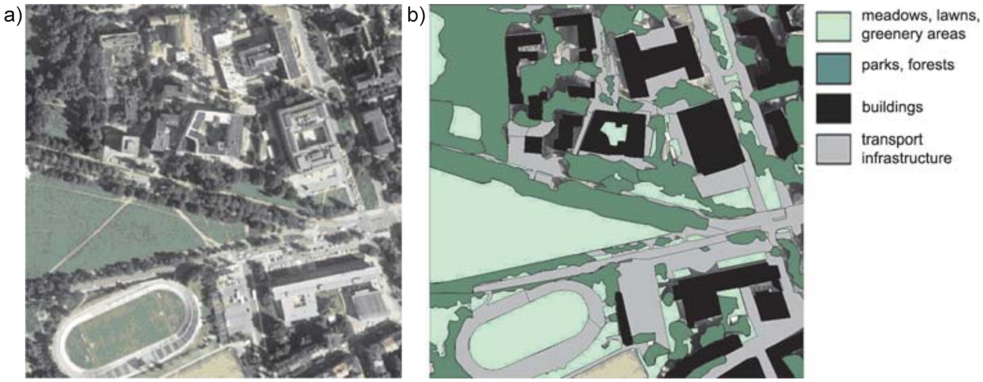

Fig. 5. 'C' testing field: a) orthophotomap; b) reference map of land use/land cover

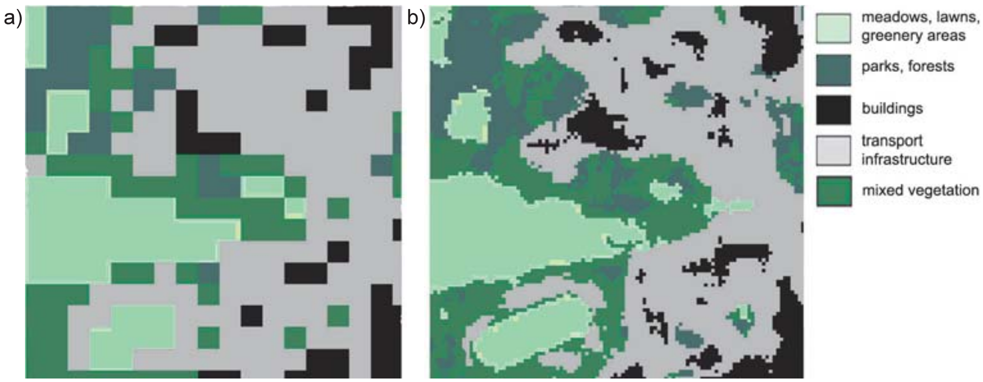

Fig. 6. Supervised classification: a) Landsat TM images; b) merged (LCM) Landsat TM and IRS images

The next step was to compare the classification results of various sets of images with the reference map. Figure 6 shows sample classification results for original Landsat images and for Landsat and IRS-PAN images merged with the use of LCM method, which gave the best results.

Table 3 presents results (consumer's accuracy for different land cover categories, total accuracy) obtained with all used techniques.

Table 3. Consumer's accuracy for each land use/land cover class (in %) obtained for original Landsat TM images and images merged with five integration techniques

Land use/land cover class	TM	IHS	WMK	HPF	LCM
meadows, lawns, greenery areas + mixed vegetation	60	63	63	62	65
parks, forests	56	75	70	66	65
buildings	26	21	24	31	29
transport infrastructure	68	49	64	59	65
total accuracy (correctly classified pixels)	50	52	53	53	55

7. Discussion

The results obtained with the use of different integration techniques and different colour composites were compared. The analysis of the results in figure 4. suggests that the number of pixels (total accuracy) correctly classified during photo interpretation increases from 70% (30m-resolution original images) to 90% (5m-resolution fused images). The choice of integration technique has weaker influence on the results. The HPF Method received the best results (about 93%) and the poorest the LCM method (about 87%). Similarly, the colour composite chosen for vectorisation is not significant. Only in case of vectorisation of the original images the CC134 seems to be the most optimal, followed by CC123. In case of the fused images (IHS, HPF, WMK) there is only 1% difference and the CC123 again takes the second place. Different results were obtained for the LCM method. The highest total accuracy was received with the CC157. It is surprising, as in the other cases this composite has the poorest results. Still, the accuracy results for this method were generally poorer than in other methods, even when the CC157 was used. This fact supports other findings in case of this method [14].

The total accuracy of supervised classification of Landsat TM images was about 50%. The fused images received results between 52% (IHS) and 55% (LCM).

The integration process did not allow including more land use/land cover categories but it improved the outlining of the objects. The increase in accuracy results by 5% seems insignificant but it means that the number of correctly classified pixels increased by 10% in comparison to the classification results for the original Landsat TM images. Additionally, if we analysed only the areas of class borders, the results would be much better. These results remain in relation to the formal parameters of spectral distortion of the fused IRS and TM images [14]. It means that the smaller spectral distortion, the better the classification result. Still, further research is necessary to confirm this fact.

8. Conclusions

The study results show that integration techniques applied to images of various resolutions enable better object outlining through visual interpretation/vectorisation. The choice of the integration technique is the key factor here. The chosen colour composite plays less significant role. For automatic classification the obtained results are doubtful and only slightly improve its accuracy.

The rasterisation of object outlines used in the present study can be replaced by a method suggested by Hejmanowska *et al.* [6]. In this procedure the area is measured many times to define the accurate location of the polygon points. In this way, we also receive information about the practical geometric accuracy of a given set of images and relate the accuracy value to a map of proper scale. By testing different integration techniques of various resolution images, it is possible to define the increase in geometric accuracy of these images. In the further research it would be advisory to increase the number of photo interpretators and test object recognition in more detail.

The tests on the applicability of fused images for classification should also consider other spectral classification methods as well as segmentation and object classification [1]. The reported results of applying the latter method suggest significant increase in classification accuracy in comparison to the classical one [22]. There has also been noticed improvement in case of fused images [9]. However, the objective of the latter study was not to find the optimal integration method.

There should be continued tests with a bigger number of integration methods. Increased amount of the analysed data (of various resolutions) would allow comprising a complementary rank list of integration procedures.

The differences between the rank lists of methods based on vectorisation and on automatic classification should also undergo further analyses. The LCM method was the best in classification and the last in vectorisation. It is necessary to provide practical measures and indicators which could allow a complex assessment of the image data information potential. The applicability of such measures proposed for example by Wald [21], Zhou *et al.* [25] and Pirowski [14, 15] has not been tested in further image processing like PCA transformation, band rationing, NDVI, classification or vectorisation. Providing such formal measures would allow simple data and integration technique selection, without the necessity of testing them each time.

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