COMPARATIVE PROPERTIES OF FOUR AIRBORNE SENSORS AND THEIR APPLICABILITY TO LAND SURFACE INTERPRETATION

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ABSTRACT:

Digital aerial photography is a widely used tool for mapping and monitoring biotopes and land use types. As technology develops new and improved sensors (e.g. higher radiometric resolution and dynamic range) become increasingly available. Comprehensive knowledge of the radiometric properties of digital imagery sensors is of special importance to adequately evaluate its applicability to land surface interpretation and mapping. This knowledge permits the processing of information in a more rigorous and controlled manner. The objective of this work was to evaluate and compare the performance of four aerial photography sensors (ADS40-1 and -2, UltracamD and DMC) in terms of their applicability to biotope type mapping in North Germany. Different biotopes and terrain features were systematically sampled and analyzed in terms of their spectral and radiometric characteristics. Qualitative and quantitative approaches were used to compare the sensor performance on different terrain features. A preliminary assessment of the camera's relative adequacy to more automated interpretation approaches, using object oriented analyses was performed. Results showed that most of the differences seem to be attributable to channel width and radiometric DN range. Some of the challenges of using object based approaches are discussed. From this study it is concluded that there is a series of factors that seem crucial to be taken into account when trying to assess interpretability in the context of LU/LC surveys. Some of them, such as edge sharpness and contrast, are already accounted for in image interpretability measures. Others, mostly related to spectral properties, such as multispectral contrast between objects and background or between neighbouring objects, need to be considered and integrated into a quantitative and more rigorous indicator.

1. INTRODUCTION

Digital aerial photography is widely used for monitoring biotopes and land use/land cover (LU/LC). Despite the development of various advanced remote sensing technologies, such as hyperspectral sensors and laser scanning, aerial photography has some properties that make it at present irreplaceable. The combination of very high spatial resolution with four channels, which includes near infrared, make aerial photography a unique resource for high detailed feature recognition, landscape monitoring and mapping.

With the advancement of technology, digital aerial photography has experienced remarkable improvements in radiometry, spatial resolution and accuracy (Ehlers et al. 2008, Petrie 2003). Simultaneously, there has been a proliferation of commercially available camera systems and products (Cramer 2005), and with that, the need to test the quality and performance of digital cameras to choose the most suitable option became increasingly evident. Most of the testing however, is normally performed focusing on the mechanical, physical or optical properties (reflected on calibration and validation issues) (Cramer 2005, Honkavaara & Markelin 2007), but rarely on the direct effects of these properties on the terrain feature interpretation.

In the context of a project funded by the Nature and Environmental Protection Office from the Schleswig-Holstein Province (LANU) in Germany, it became evident that to assess the camera's appropriateness for landscape monitoring it was necessary to establish reliable object and feature recognition and interpretation standards. In trying to define lower biotope categories, in which detailed features need to be identified, slight differences in shape, texture or color between images from different cameras became crucial.
The objective of this study was to determine the extent to which differences in camera properties may influence the terrain feature recognition for biotope and LU/LC monitoring purposes.

Leica Geosystems ADS40 1st and 2nd generations, Intergraph DMC and Vexcel UltracamD were compared in this study in terms of radiometry, spectral properties, geometric accuracy, and the effects of pansharpening, mosaicking, swath overlapping, as well as some data handling considerations. In this paper, mostly results on radiometry, spectral and spatial resolution aspects are presented, as they influence biotope and LU/LC surveying and monitoring.

The main difference between the camera systems under study is that ADS40 is a line scanner, whereas DMC and Ultracam are frame camera systems. Many operational and image quality differences, such as geocorrection and spatial accuracy, and the need of pansharpening, are derived from these two types of camera architecture. Other important differences are given by the radiometric and spectral properties, and have been reviewed elsewhere (Petrie 2003, Poon et al 2006).

2. MATERIALS AND METHODS

2.1 Aerial photography

The aerial photography images were taken at Schleswig-Holstein to fulfil the requirements of the LANU agency for a periodical monitoring of the LU/LC of the entire state. The flights of ADS40-1 and Ultracam were carried out at the

Eiderstedt Penninsula area on August 2004 (20 cm spatial resolution) and May 2005 (10 cm spatial resolution), respectively. ADS40-2 and DMC images were taken in the area of Travetal, on August (20 and 10 cm, multispectral) and September (40 and 20 cm, multispectral) 2006, respectively.
Images were geocorrected for the analyses, but non-corrected versions were also used as reference to check for potential effects of the geocorrection itself on image radiometry and quality. Analyses were carried out on both, CIR and RGB images, however, for brevity reasons most of the studies reported here are on CIR images. In what follows, infrared, IR and NIR are used interchangeably.

2.2 Analyses

Aerial photos were subset (880 and 150 ha for Eiderstedt and Travetal, respectively) for the analyses, trying to include the highest variety possible of land cover types, with special consideration for protected biotopes.

Main biotopes or LU/LC types were delineated to be analyzed separately. Entire biotope areas and subsets of these were sampled to extract statistics and histograms for all the multispectral channels of each pair of cameras, to determine the radiometric characteristics of the sensors at each cover type. Assisted by observation *in situ*, ground features needed to define lower biotope levels (e.g.: river banks, tree species, small water bodies, presence of livestock) were carefully identified on the photos. From these features, those that are especially stable over time were characterized by texture, radiometry and spectral properties, and compared between different cameras.

Ground features whose size is on the limit of the spatial resolution of the images were identified and analyzed to test the sharpness of the images at the highest possible resolution. Differences in automated feature recognition capacity between ADS40-2 and DMC were investigated by a segmentation-classification approach. After trying different methods in various biotope types a 1-ha area of broadleaf-conifer mixed forest was selected. An automated, hierarchical segmentation was carried out on the 4-band images of the area. Subsequently, two semi-automated classification procedures, one focusing on shape and the other on color, were performed, in order to discriminate between tree types and to identify individual crowns. For the shape-based classification, a simple criterion based on a combination of pixel DN thresholds and mean difference between neighbouring pixels was used to classify crowns against the background. Thresholds were set independently for each camera and specific values were assigned based on observations made on a single tree. The resulting classified rasters were given to independent researchers to identify individual crowns and tree types across the entire image. For the color-based classification, a series of pixel DN thresholds was used to identify different regions of each tree crown, and then merged into a single class. A pixel maximum difference criterion was used to discriminate broadleaf from conifer crowns.

Pixel maximum difference:

$$\frac{\text{DN max } (i,j,k,l) - \text{DN min } (i,j,k,l)}{\Sigma \text{ mean DN } (i,j,k,l) / \text{Number of layers}}$$

Where DN=Digital Number, and i, j, k, l, are the image layers used.

3. RESULTS AND DISCUSSION

3.1 ADS40-1 and Ultracam

In all the cover types sampled Ultracam shows a wider range of DN values than ADS40-1, as exemplified by histograms of the red and NIR channels (Figs. 1 and 2) taken from a sample of trees. To investigate the relationship between the width and overlap of spectral channels of a sensor and the image frequency histograms, a series of pixel samples of increasing size (ten to several hundreds) were taken at spectrally homogeneous areas (tree crowns, pastures, water bodies, etc). From these samples, statistics and histograms were derived and compared between sensors. It was observed that within spectrally homogeneous areas wider spectral channels tend to correspond to higher pixel DN standard deviations. A possible explanation is that a wider spectral channel tends to capture longer portions of the pixel's spectral curves producing higher deviations respect to the average DN value of the sample. In contrast, a narrower channel would capture small portions of the spectral curves, which increases the probabilities to sample more similar values between pixel spectra.

Evidently, the interaction between spectral channels and pixel reflectance values highly depends on the spectral shape and homogeneity of the target, and to establish a relationship more rigorously a comparison between multi- and hyperspectral curves of a given terrain feature should be carried out. However, the claim that wider channels would tend to produce wider frequency histograms within certain conditions, does seem to be justified.

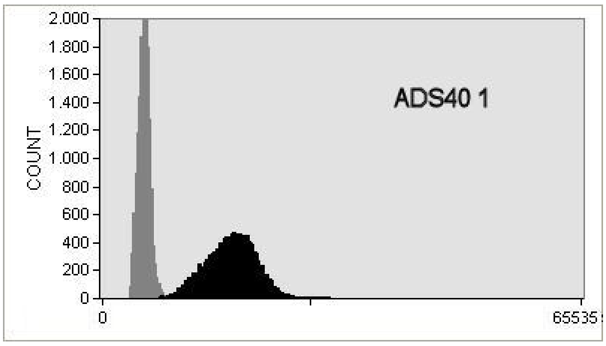

Figure 1: ADS40-1: Histograms from tree canopies, for the infrared (black) and red (grey) channels.

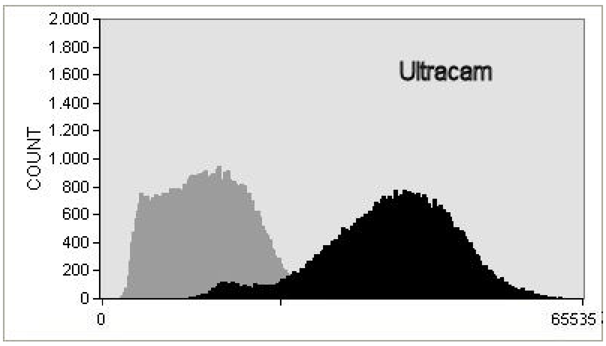

Figure 2: Ultracam: Histograms from tree canopies, for the infrared (black) and red (grey) channels.

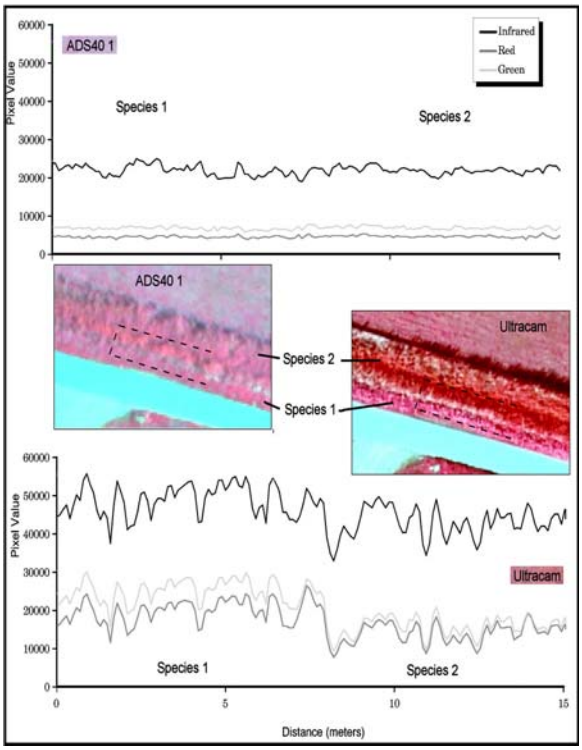

Figure 3: Spectral discrimination of plant species in ADS40-1 and Ultracam. Dashed lines on pictures indicate where the spectral profiles were taken.

As shown in Fig. 3, the CIR spectra of Ultracam show different average values for Species 1 and 2, whereas for ADS40-1 the spectral average between species is very similar. This better discrimination between some plant species may also be related to the wider channel of the sensor, depending on the specific characteristics of the plant spectra.

The lower degree of histogram overlap between IR and red in ADS40-1 (Fig. 1) compared to Ultracam, also seems to correspond to the difference between shapes of the spectra of the IR and red in Fig. 3, because narrower channels tend to capture more different portions of the spectral curve. In contrast, all three channels in Ultracam have highly correlated profiles. The relatively lower correlation between bands can help discriminate better between other surfaces, as shows Fig. 4, in which the dike structure appears more clearly depicted in the ADS40-1 IR-red composite.

In terms of ground feature resolution, an analysis of a painted line on a parking lot shows that Ultracam has a higher definition than ADS40-1. A sample of pixels representing a transition between "normal" asphalt background and a painted line, shows that there is a much steeper spectral change in Ultracam, which results in a sharper object (Figs. 5 and 6) that not only contrasts better with the background asphalt, but also appears as a narrower stripe of two to three pixels wide. This spectral change is conceptually equivalent to the relative edge response (RER), which is a parameter used to measure image interpretability (Ryan et al. 2003). There are two additional factors that hinder ADS40-1 resolution ability. One is the fact that the infrared channel shows a particularly lower sensitivity; and the other is that the higher pixel values of the red channel, which correspond to the center of the painted line, do not spatially match with the green and infrared, contributing further to the blurring of the image object (Fig. 5).

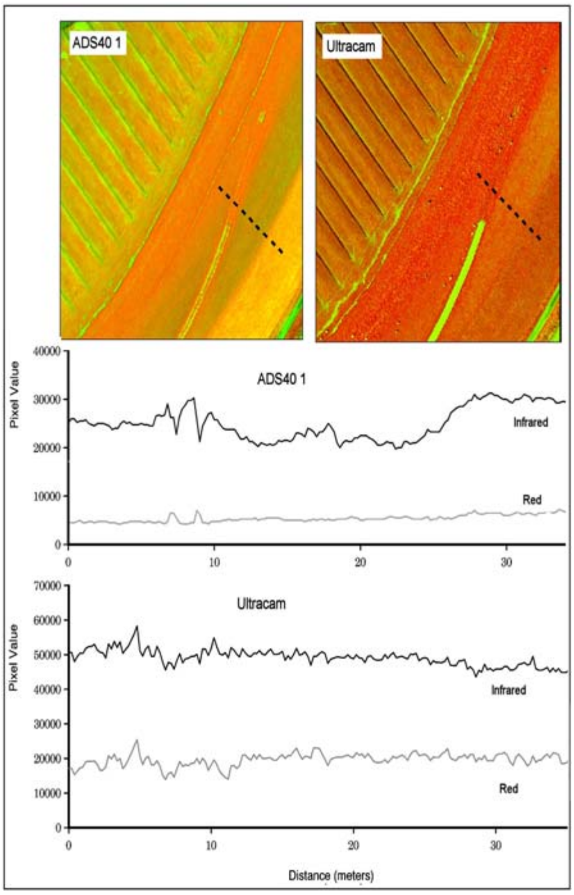

Figure 4: Terrain feature discrimination due to variations in spectral profiles between bands for ADS40-1 and Ultracam. Photos are composites of infrared (red color) and red (green color). Dashed line indicates where the spectral profiles were taken.

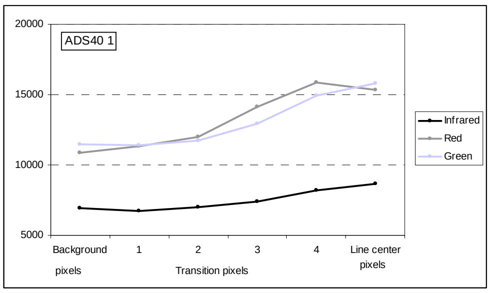

Figure 5: ADS40-1: Transition spectra between asphalt ("background") and a painted line center on a parking lot. Each pixel category represents an average of 20 pixels.

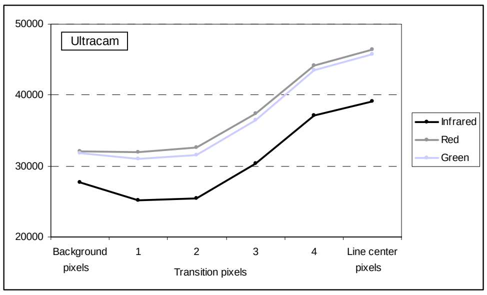

Figure 6: Ultracam: Transition spectra between asphalt ("background") and a painted line center on a parking lot. Each pixel category represents an average of 20 pixels.

3.2 ADS40-2 and DMC

In all the sampled cover types there was more overlap between bands in DMC in comparison with ADS40-2. ASD40-2 showed a wider DN distribution in NIR and narrower in red and green compared to DMC (Figs. 7 and 8).

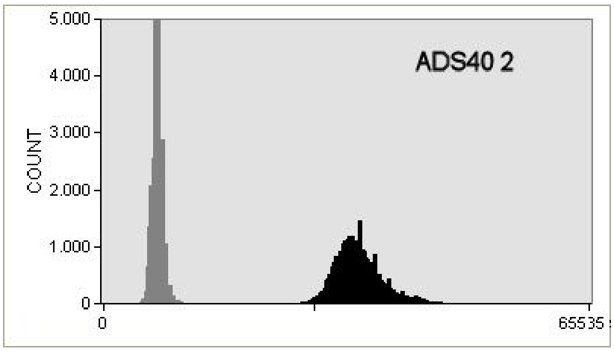

Figure 7: ADS40-2: Histograms from a field sample, for the infrared (black) and red (grey) channels.

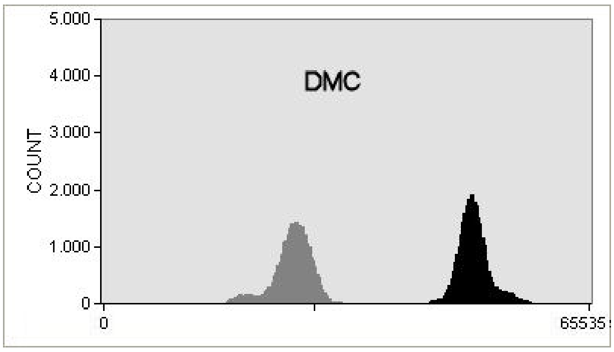

Figure 8: DMC: Histograms from a field sample, for the infrared (black) and red (grey) channels.

In terms of tree identification based on shape, from the overall scene point of view, DMC performed slightly better on the automatic segmentation and classification of trees. In the DMC image more individuals could be successfully identified as either conifer or broadleaf, because relatively more conifer trees showed the typical radial configuration, as opposed to the irregular, compact appearance of broadleaf canopies (Fig. 11).

By inspecting the DMC and the ADS40-2 scenes, however, it became evident that most of the trees in ADS40-2 had an orientation closer to the azimuth (trees were vertically seen), and in this way fewer conifer branches were exposed, contributing to the appearance of a more irregular shape, which made some of them look similar to broadleaf canopies (Fig. 12).

When individual tree canopies were analyzed in detail, the ADS40-2 and the DMC showed very similar performance in their ability to discriminate between species or identify individual trees based on shape. This means that other than the problem of tree canopy inclination, possible differences between the sensors in terms of spatial resolution or spectral characteristics would not have a significant effect on automated object recognition.

In terms of tree identification based on spectral properties, both, ADS40-2 and DMC performed similarly with respect to their ability to differentiate between conifer and broadleaf canopies. ADS40-2 showed a slight tendency to over represent broadleaf occurrence (about 8% of broadleaf canopy area commission error), whereas DMC tended to under represent them (less than 5% broadleaf canopy area omission error). These differences are not necessarily related to the camera's ability to discriminate tree species as discussed above. Spectral differences between conifer and broadleaf are much higher than between two broadleaf species, and the possibility of discrimination between tree types on a scene has more to do with the natural spectral variability typically found across an entire scene, than just the camera properties. The criteria to choose between forest type, mainly the pixel maximum difference, depends on the threshold chosen for each camera, and thus it is difficult to be used to compare cameras.

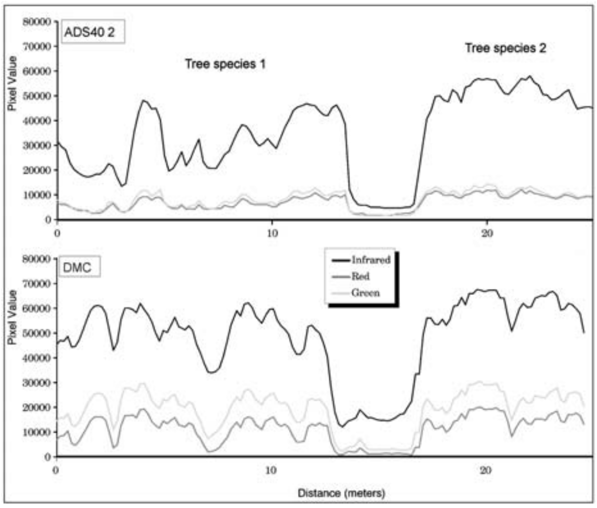

Figure 9: Spectral discrimination of plant species in ADS40-2 and DMC. Profiles show the reflectance of the canopies from two different tree species separated by a portion of a shadow.

The advantages of having a broader DN distribution can be noticed when seeing how the NIR band form ADS40-2 discriminates two tree species better than DMC (Fig. 9). The other bands, which have narrower distribution, do not discriminate so well. Differences in ADS40-2 NIR between species can be directly visualized (Fig. 10) and contrasted with the relatively low discrimination degree of DMC NIR. As suggested by Fig. 9 and shown in Fig. 10, the ADS40-2 red channel shows much less differences between species than the NIR.

Ground feature resolution differences between ADS40-2 and DMC could not be tested due to the lack of adequate ground structures that could be clearly compared. To that end, adequate features need to be a few pixel size, and be present in similar orientation in both images. They have to be flat to be independent of the camera azimuth, and to be stable enough in time to be independent of the flight date. Human-made features, frequently good candidates for this comparison, were rare in the Travetal scene. A careful observation of narrow features in the ADS40-2 scenes, such as road lines and hedges, however, indicated that there was no spatial shift between channels, as observed in ADS40-1. This contributes to a better object definition.

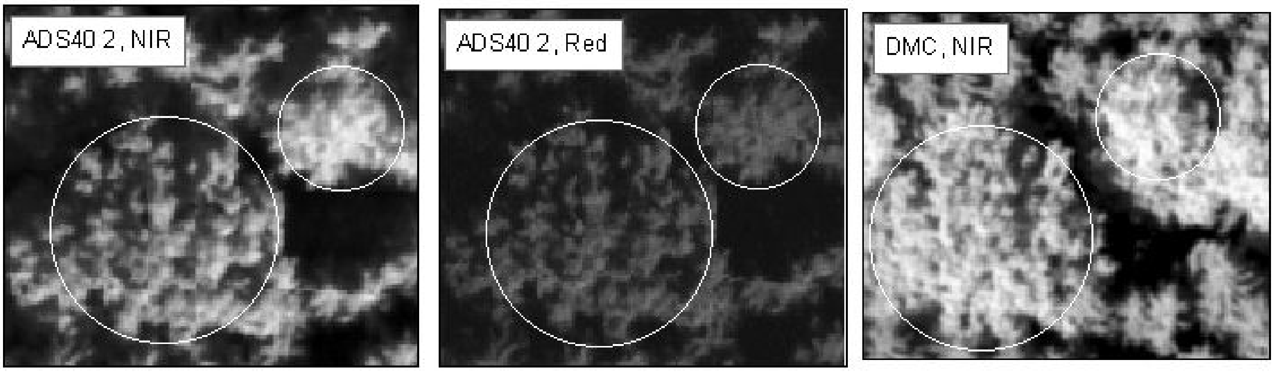

Figure 10: Spectral discrimination of plant species in ADS40-2 and DMC. The large circle shows one tree species, the small circle, another.

Figure 11: NIR image of canopies of a typical conifer (left, down) and a broadleaf (right, up).

4. CONCLUSIONS

The main purpose of this paper was to provide a preliminary evaluation of the relative ability of commercially available digital camera sensors to provide detailed terrain information, especially related to LU/LC surveys. This comparison stresses the relative advantages and disadvantages from the point of view of the end user, who often has a limited knowledge of the physical or technical aspects of the cameras, and sometimes, even of the image pre-processing.

Based on this study, it can be concluded that there are three fundamental aspects to take into account to identify and discriminate between terrain features: a) the DN range of each band, b) the degree of overlap between bands, and c) the degree of correlation between spectra of the different bands.

ADS40-1 showed a lower capacity to resolve small features, a problem that seems to have been at least partially addressed in the 2nd generation (Honkavaara & Markelin 2007). As seen in the particular case of individual trees, both, DMC and ADS40-2 showed a similar potential for automated object recognition.

One of the main limitations of our study is that not all four camera systems were tested in the same area, and none of the

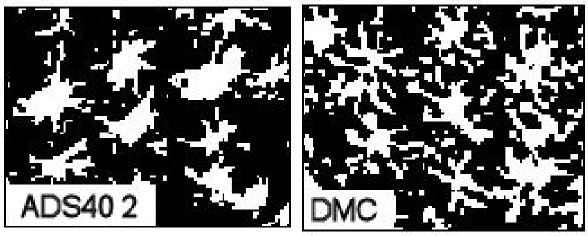

Figure 12: Comparison of segmentation results between ADS40-2 and DMC. Although both pictures show a group of conifer trees, DMC segments (white) show a more defined typical conifer structure.

flights was carried out simultaneously, which limits our control over terrain changes. Thus, the results cannot be considered a rigorous test, but rather indicators of trends in camera differences and, consequently, their potential advantages or disadvantages.

Image interpretability (ImIn) has been proposed as a way to assess the ability of an image to provide relevant and accurate information. Since the problem of ground feature interpretation is central to land cover/land use monitoring, ImIn is closely related to the kind of problems presented in this study. ImIn can be measured both, qualitatively (NIIRS scale in Irvine & Leachtenauer 1997) or quantitatively (Ryan et al. 2003). Unfortunately, however, as noted elsewhere (IRARS 1995), none of these scales do explicitly incorporate spectral information, which in our camera comparison study is of fundamental importance. An ideal camera performance measurement should integrate all the information that an expert is able to use in image interpretation, and provide a value to be compared with other images.

Segmentation and classification algorithms are designed to reproduce the way the human brain processes and interprets visual information to recognize relevant terrain features. This is conceptually closer to the interpretability issues involved in image quality comparison. The problem with segmentation-classification is that due to the intrinsic complexity of the information contained in high resolution images the analysis can be also vey complex, thus the need of user's involvement is frequently high, and in turn the control and understanding of the process can be severely compromised (Schiewe et al. 2001). For example, even a relatively simple segmentation approach, as the one used in our study, required the use of threshold specific to each camera, reducing the validity of the comparison of camera performance.

From our study it becomes evident that there is a series of factors that seem crucial to be taken into account when trying to assess interpretability in the context of LU/LC surveys. Some of them, such as edge sharpness and contrast, are already accounted for in ImIn measures. Others, mostly related to spectral properties, such as multispectral contrast between objects and background or between neighbouring objects, need to be considered and integrated into a quantitative and more rigorous indicator. This indicator would allow for the rapid and reliable comparison of multispectral images, without the need to resource to complex segmentation and/or classification procedures. Ideally, it could also guide in new digital camera developments.

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