

## **ARCTIS – analysing hyperspectral datasets**

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In archaeology, several studies have demonstrated that airborne imaging spectroscopy (AIS), also known as airborne hyperspectral remote sensing, has a huge potential for airborne prospection. AIS overcomes the deficits of conventional and multispectral imagery and therefore holds the potential to enhance the visibility of soil colour differences and plant stress.

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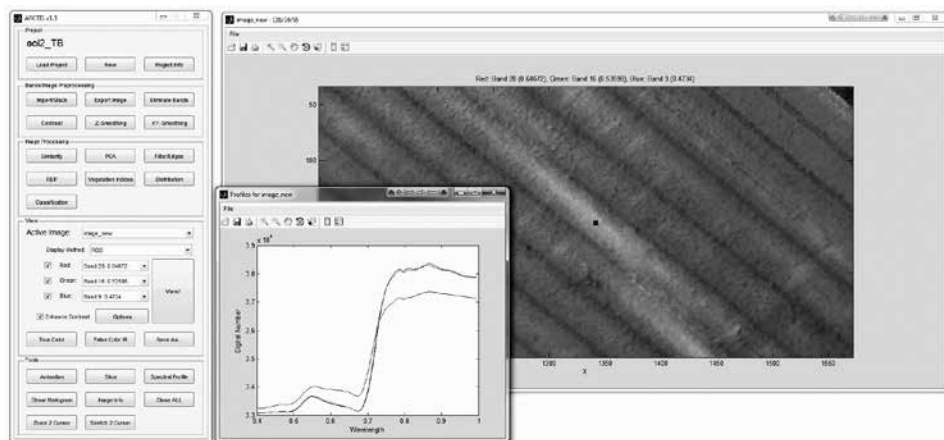


Fig. 1. Display of reflectance curves of user-selected pixels is a standard tool

However, to fully exploit this potential, a number of inherent problems have to be addressed by the image analyst: (1) the large number of spectral bands which need to be inspected; (2) the inherent data redundancy in AIS data sets; (3) the relatively low signal-to-noise-ratio of the imagery, especially when acquiring AIS data with ground-sampling distances (GSD) smaller than one meter; (4) the fact that available software packages do not provide tools specifically aiding data reduction for archaeological feature detection (e.g., red-edge detection and parameterization). Also, the most fruitful ways to visualize the data for a specific scientific investigation have to be explored.

For research in archaeological prospection, suitable software solutions which address these issues are needed. These packages should focus on the overall workflow rather than the technical expertise needed to enhance the visibility of plant and soil spectral differences. Therefore, the toolbox ARCTIS (ARChaeological toolbox for imaging spectroscopy) was programmed in MATLAB<sup>®</sup> to address the above mentioned problems and requests (Doneus *et al.* 2014; Atzberger *et al.* 2014). ARCTIS was developed in cooperation between the Department of Prehistoric and Historical Archaeology of the University of Vienna and Vienna's University of Natural Resources (BOKU). The main aim of this specific AIS toolbox is to enable users to inspect, visualize and analyse hyperspectral data sets to highlight possibly occurring archaeological visibility marks (of which crop/vegetation marks are the most abundant). It was, therefore, necessary to develop a software for the specific needs of archaeologists.

First of all, a user-friendly GUI had to be designed so that even a non-specialist in remote sensing could work with ARCTIS in a straightforward way. Based on the authors' conviction that only high spatial resolution datasets (GSD < 1 m) will be useful for archaeological prospection, the toolbox includes a Whittaker smoother to reduce the sensor noise which becomes apparent when sampling the earth with small GSDs in very small spectral bands. Despite removing the spectral noise, the Whittaker smoother (Eilers 2003) preserves the complete shape information of the observed spectral signature. Each AIS pixel is smoothed independently

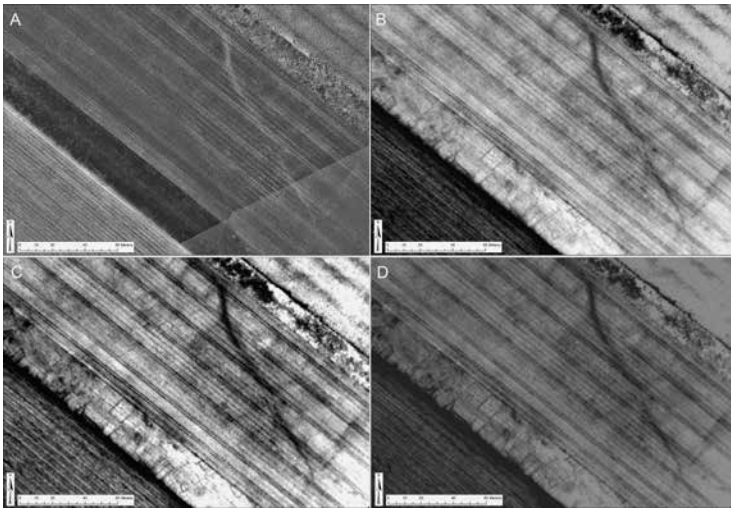


Fig. 2. Data from Carnuntum, Lower Austria, acquired on May 26, 2011. Size of depicted area: 230 x 154 m. (A) Conventional orthorectified aerial image, acquired in the visible spectrum. GSD of 0.1 m; enhanced using contrast limited adaptive histogram equalization (CLAHE); (B) false colour composite created by means of the REIP algorithm (R = band 1 (wavelength), G = band 2 (slope), B = band 3 (reflectance value)); (C) rate parameter  $b$  of the gamma distribution fitting; (D) normal distribution fitting (R = NONE, G = band 2 (s), B = band 1 (m)). GSDs of (B), (C) and (D): 0.4 m. Figures B, C, and D were subject to the same histogram stretch by means of standard deviation (from Doneus *et al.* 2014)

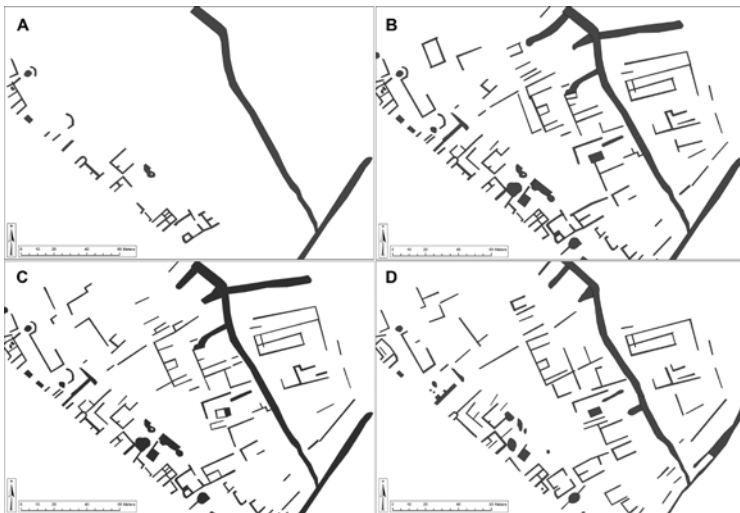


Fig. 3. Mapping of visualizations from Fig. 2: (A) orthophotograph; (B) REIP, (C) gamma distribution fitting, (D) normal distribution fitting (from Doneus *et al.* 2014). Size of depicted area: 230 x 154 m

along the z-axis (i.e., spectral dimension). After this computation, the smoothed values are written into a new image. The latter thus holds all the smoothed spectral signatures. Because the smoother treats all bands as if they were equally spaced in the wavelength range, the number of input bands equals the number of output bands. Moreover, the smoother is easy to parameterize and balances fidelity to the data and the roughness of the smoothed curve.

Furthermore, ARCTIS needed several methods to identify information-rich layers. This task was accomplished through several subtools. First, interactive visualization of the AIS bands is possible and allows the user to mine their hyperspectral data and identify the most useful spectral bands for discriminating soil and vegetation marks. As a standard tool, the reflectance curves of user-selected pixels can be displayed. More importantly, the entire image cube can be visualized along user-selected vertical or horizontal slices. A horizontal slice, for example, corresponds to all data (in column and layer direction) along a fixed row number. If located above a known soil or vegetation mark, this permits the user to detect band numbers (wavelengths) where these marks have their contrast maximised in respect to their surrounding matrix. Because the human visual system is very effective in recognizing structures and movements, a number of animated visualization tools have been added as well. Those permit the layers of the active image to be displayed sequentially (and repeatedly) with a user-specified frequency.

Second, well known image processing techniques are offered in the toolbox. Those vary from vegetation indices, over-edge detectors to data compression techniques such as principal component analysis (PCA). In the case of ARCTIS, PCA is based on selected sample areas with known vegetation marks.

Finally, also a variety of very powerful tools for unique spectral data mining have been developed. One of those is the calculation of inflection points in the red-edge waveband and along the shoulders of other absorption bands. A number of studies have demonstrated the added value of detecting inflection points in the spectral shapes of vegetated pixels (e.g., Darvishzadeh *et al.* 2009). Despite the long-lasting knowledge about the prospects of this indicator, currently no commercial software has implemented suitable algorithms. The inflection point algorithm included in ARCTIS identifies for each AIS pixel the location (in terms of band number) of the highest (absolute) gradient in the spectral profile. In addition to this “inflection point” (first output layer), the algorithm also outputs two additional indicators linked to this point: the value of the gradient itself (second output), and the level of reflectance for the wavelength of maximum gradient (third output).

Additionally, ARCTIS allows the calculation of novel distribution fittings. They can yield new insights into crop vigour and vegetation stress. Their archaeological potential has already been investigated in depth (Doneus *et al.* 2014).

To help the image analyst to remember all individual processing steps, all functions and their parameters that are applied to each image file are logged into an ASCII-based history file. History files inherit their name from the image file to which they correspond and are located in the same folder. When ARCTIS creates a new image from a previously processed dataset, it will extract the original history information and store it, together with new history info, along the new image file. In this way, all functions and parameters that produced a given image are included in its history file. This makes the whole processing chain traceable and repeatable.

Given the fact that many of its residing processing and visualization tools cannot be found elsewhere

and commercial software is often costly and less straightforward to use, the authors decided to make the toolbox and its source code freely available under a creative commons license for all interested parties (via download from <http://luftbildarchiv.univie.ac.at>). Together with some test datasets, this open access will enable interested students and remote sensing professionals to become acquainted with AIS, while other scientists can contribute with new algorithms to further expand and even optimize ARCTIS.

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