POTENTIAL OF THE ADS40 AERIAL SCANNER FOR ARCHAEOLOGICAL PROSPECTION IN RHEINAU, SWITZERLAND

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ABSTRACT:

The goal of this research is to test an empirical line radiometric calibration of airborne digital scanner ADS40 data from Leica Geosystems, for remote sensing applications in general and to demonstrate the potential of ADS40 data for archaeological prospection in detail. In this study we present the first results of multitemporal flight campaigns with two different generations of ADS40 sensor head systems and simultaneous 'traditional' oblique airborne photo flights over the archaeological test site Rheinau in northern Switzerland. In a first flight campaign in July 2006 the ADS40 of the Swiss Federal Office of Topography (swisstopo), a first generation SH40 camera head, was used. A second flight campaign in September was carried out with the ADS40 sensor, operated by the manufacturer Leica, with the new second-generation SH52 head. Spectral signatures of several ground targets were taken in parallel with a field spectrometer and a field survey was carried out.
The ADS40 data sets were geometrically corrected with respect to national map sheets. A radiometric calibration of the spectral bands was applied with an empirical line approach, including the ground spectra. Archaeological interpretations of both ADS40 data sets and of oblique aerial images were compared. The visible structures are predominantly old house-forms with cavities and fosses, historic soil withdrawals, remaining structures from agriculture treatments, historic harbour facilities and refilled riverbeds from the Neolithicum until today. The visibility of the archaeological structures in ADS40 data and oblique photos was compared. It was shown, that thanks to the higher radiometric performance of ADS40, additional elements were detectable. ADS40 data is shown to be a good choice for archaeological prospection. Every three years, a complete nationwide coverage of Switzerland with 25cm ground sampling distance will be flown operationally by swisstopo, a perfect alternative or even substitute in aerial archaeological prospection with traditional aerial image survey.

1. INTRODUCTION

Aerial photographs have been used for archaeological prospection for more than a century. The first aerial photos of an archaeological site showed excavations within the Forum in Rome in 1899. Lieutenant Philip Henry Sharpe took the first aerial photographs of Stonehenge, in 1906 from a balloon platform. During World War I, the German military aviator Theodor Wiegand used the first time systematically photographs from airplanes for aerial archaeology (Watziger, 1944). O.G.S. Crawford in England is said to be the inventor of scientific aerial archaeology (Crawford, 1924). After World War II most of the European countries started with archaelogical prospection based on aerial black and white, later on true-colour and false-colour-infrared films.
Exposed ruins can easily be mapped from above with aerial photographs. Subsurface residues may be discovered for example by marks on the terrain, due to altered density, composition and humidity of the topsoil, by variations of the overlying vegetation layer, variation in topography or particulars of frost and snow (Wilson, 2000; Evans and Jones, 1977).
Aerial archaeology usually relies on dedicated flights with (handheld) cameras at oblique acquisition angles. The data acquisition setup accounts for various parameters, causing archaeological signatures and effects in the photographs as for example different illumination angles, best point in time and season, directional effects of reflected or emitted radiation, scale and spatially limited investigation site or weather and humidity conditions. Dedicated flights are costly, demanding and go beyond the scope of the finances and technical capabilities of most archaeological prospection offices, which are organized rather on a regional and local (e.g. Switzerland), than national level. The aerial photographs of national aerial mapping surveys are alternatively used, despite the fixed acquisition geometry (nadir), interval and time in season. The Swiss Federal Office of Topography (swisstopo) disposes of aerial photographs beginning in 1927 and in a six years acquisition interval since the fifties. In reality, these aerial photographs are seldom used for archaeological prospection and mapping. Apart the mentioned restrictions in data acquisition conditions, the photographic film shows a contrast dynamics of not exceeding seven bit which is not sufficient to detect reflection differences in shadowed areas. However the data storage capacity of the film excels all the new (digital) imaging and archiving techniques.
For a short time airborne digital high-resolution cameras are replacing photographic analog cameras and are widely used for cartographic mapping (Petrie & Walker, 2007). These digital imaging devices are spectrally and radiometrically superior to analogue film cameras. They have the potential for remote sensing applications and archaeological prospection in specific (Beisl, 2006; Aqdus et al., 2007).
In 2005 the Swiss Federal Office of Topography started using the airborne digital sensor system ADS40 from Leica for topographic mapping (Sandau et al., 2000). Swisstopo will

switch the next years entirely from analog, aerial photographs to full digital data acquisition in a three-years nationwide coverage. The ADS40 system is a radiometrically stable instrument predestined for archaelogical applications. The recently introduced second generation of instrument sensor heads (SH52) provides four spectral bands (blue, green, red and near infrared) and a panchromatic (pan) band, all in stereo and with equal high spatial resolution and a radiometric resolution of 12 bit (Petrie & Walker, 2007).
The main objective of this paper is to investigate the required radiometric preprocessing of ADS40 data for remote sensing applications in general and to demonstrate the potential of ADS40 data for archaeological prospection in detail. We present the first results of a multitemporal flight campaign in 2007 with two different ADS40 system heads and will compare the results to findings with 'traditional' oblique airborne photo flights over the archaeological test site Rheinau in Northern Switzerland.

2. TEST SITE RHEINAU

The rural town of Rheinau is located in Northern Switzerland, at the border to Germany, a few kilometers downstream the famous cascade of the Rhine river. The river forms two small peninsulas, the German Altenburg area in the northeast and the Swiss Rheinau region in the southwest (Fig. 1).

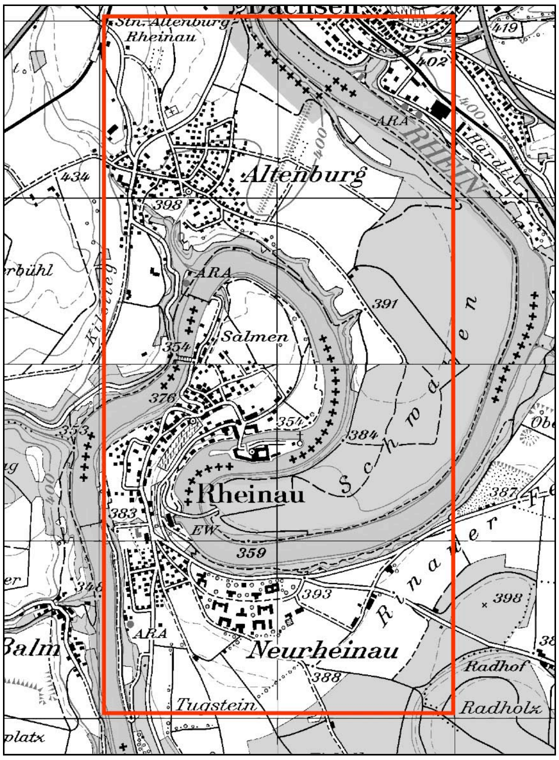


Figure 1. The Rheinau test site, ©swisstopo, 2007

First traces of settlements are dated back to the Mesolithicum. The Rheinau peninsula was separated from the foreland in the Bronze Age, the Altenburg peninsula in the pre-Roman Iron Age, by still detectable walls. The Celtic people founded two town-like settlements (Oppida) on the Altenburg (2nd century BC) and the Rheinau (2nd quarter of 1st century BC) site. Many archaeological structures and items of the Celtic period, ending 3rd quarter of 1st century AD, were already found. First Roman archaeological discoveries are dated early 1st century AD. Last traces of Roman settlements can be dated to the year 454 AD. The period of the 5th century is almost not documented. The Benedictine Abbey of Rheinau, founded 778, is one of the most magnificent edifices of High Baroque architecture in Switzerland and today the Rheinau's landmark.
Since the second half of the 19th century archaeological and historical prospection in and around Rheinau were accomplished in different intensity and with changing emphasis. In the beginning, the focus was set on fortifications and remains of the settlement of the Celtic time. In recent time the focus was put also on the Benedictine Abbey and the medieval small town Rheinau. Rheinau turned recently to a focal point of archaeological prospection for the Archaeological service of the Canton of Zurich, in cooperation with the German partners. All aspects of archaeological prospection techniques are currently under investigations, including non-destructive remote sensing techniques such as aerial photography, digital scanners, Radar and Lidar, ground based Radar, geoelectric and geomagnetic measurements, as well as invasive techniques like probing and excavations. The present investigation is embedded in the current integrative research.
The overall spatial extent of the test area is 2 km (east–west) by 4 km (north–south). The terrain heights range between 340m and 425 m above mean sea level.

3. FLIGHT CAMPAIGNS

3.1 ADS40 sensor system

The ADS40, the digital aerial pushbroom scanner from Leica Geosystems, Heerbrugg, Switzerland, was first launched in 2000. A detailed description may be found in (Sandau et al., 2000; Leica Geosystems, 2007). The ADS40 is a single optic system with a focal length of 62.7mm and a field of view of 64° across track (Fig. 2). The sensor head has individual CCD lines for pan, red, green, blue, and nir bands with 12'000 pixels and 6.5µm pixel size (Sandau et al., 2000; Beisl, 2006). The spectral bands are narrow, non-overlapping and have a response characteristic with almost a rectangular shape and a radiometric resolution of 12 bit (Beisl, 2006).

Sensor head type	**SH40**	**SH52**
Focal length	62.7 mm	
Sensor type	Pushbroom line CCD	
Total field of view (across track)	64°	
CCD across flight line	2x12'000 (pan) 12'000 (ms)	
Sensor size	6.5 µm	
Bands		
wavelength (rectangular for multispectral, trapezoidal for pan)	blue: 430 - 490 nm	
	green: 535 - 585 nm	
	red: 610 - 660 nm	
	nir: 835 - 885 nm	
	pan: 465 - 680 nm	
nadir looking bands	red, green, blue	nir, red, green, blue
	pan	pan
oblique looking band	red +14°	
	green +16°	
	nir +18°	
	pan -14.2°	nir, red, green, blue, pan (-10°)
	pan +28.4°	pan +40°

Figure 2. Technical characteristics of ADS40 SH40 and SH52 (Sandau et al., 2000, Leica Geosystems, 2007)

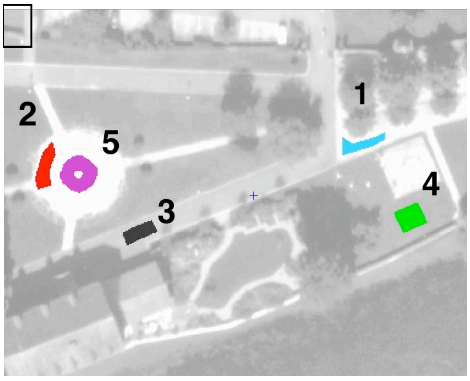
In the present study, two flight campaigns were performed with different sensor heads: The ADS40 first generation head SH40 was operated by the Swiss Federal Office of Topography, mounted on a Super King Air plane. The SH40 head consists of four bands in nadir direction (red, green blue and panchromatic), three bands in forward direction (nir, red and green) and two additional oblique panchromatic bands (Fig. 2). The oblique acquisition angle of the nir band, compared to the nadir RGB bands affects the SH40 data interpretation adversely. Therefore Leica developed the new second generation sensor heads SH51 and SH52 with all spectral bands in nadir as well as in single oblique, backward (-10) viewing angle (Leica Geosystems, 2007) (Fig. 2). The second flight campaign was performed with Leica's own ADS40 with a second generation head SH52. The system was installed on a Pilatus Porter aircraft.

3.2 ADS40 flight campaigns and preprocessing

The first ADS40 flight campaign in the test site Rheinau was made by swisstopo on 16 July 2007, 12:19h local time with the SH40 sensor. The second campaign, flown with the sensor head SH52 by Leica Geosystems, was made on 13 September 2007, 12:40h local time. Both acquisitions were made on a 2400m flight level above ground in north-south direction, achieving a minimal ground sampling distance of 25cm. The data onboard storage was carried out without compression, not to loose any radiometric performance and traceability.
Swisstopo and Leica Geosystems individually made the geometric preprocessing of the data with Leica's Gpro 3.0 software (Beisl, 2006). The datasets were geometrically corrected to fit the Swiss national map reference system, an oblique, conformal cylinder projection (Mercator projection), together with the Bessel ellipsoid 1841. Elevation information was taken from the digital 2m-raster, high precision, laser scanning based surface model (DOM-AV) from swisstopo, whereas official cadastral points served for absolute geometric reference.
The digital sensor values were converted simultaneously to the geometric correction into linearly scaled at sensor reflectances, applying the sensor specific bandwise response functions, supplied by the manufacturer Leica. The resulting linearly scaled sensor reflectances are also known as calibrated digital numbers (CDN). This radiometric calibration process is described more in details in (Beisl, 2006).

3.3 Oblique aerial photographs and ground reference data

In order to better evaluate the potential of ADS40 data for archaeological mapping, traditional oblique aerial photos with a handheld digital camera, were taken onboard a small plane, almost simultaneously from various regions and archaeological signatures in the test site. The July photographs were acquired two days after the ADS40 SH40 overflight, the September pictures the same day of the ADS40 SH52 flight.



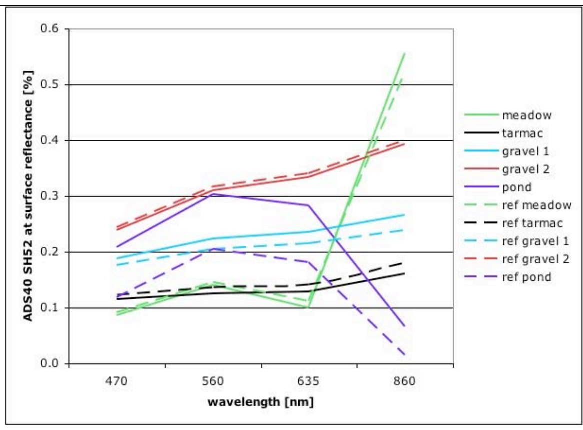
1 gravel 1
2 gravel 2
3 tarmac
4 meadow
5 pond

Figure 3. Reference targets on the Rheinau Benedictine Abbey island, September 2007

On 13 September 2007, the date of the SH52 campaign, extended fieldwork was carried out. Beside a general landuse/landcover investigation, five different ground targets were spectrally characterised with a 'FieldSpec® 3' spectrometer, built by ASD Inc. The handheld spectrometer contents three bundled single detectors ; one for the 350-1000 nm range with 3nm spectral resolution and two other ones for the 1000-2500 nm range with 10 nm resolution (ASDInc. 2007). The reference targets were selected on the island beside the Benedictine Abbey of Rheinau, having three calibration targets (e.g. tarmac, gravel 1 and gravel 2), a typical vegetation target as reference (meadow) and a water target in a pond, influenced by a fountain (Fig. 3).

4. EMPIRICAL LINE CORRECTION OF ADS40 DATA

Calibrating the SH40 data from July 2007 and the SH52 data from September 2007 to physical units such as reflectances is a prerequisite for a multitemporal analysis and/or a comparison of the detectability of archaeological structures by season and sensor systems (Teillet, 1986). The radiance measured by the sensors is influenced for example by the atmosphere, neighborhood and directional reflection effects of the targets. A correction approach based on a radiative transfer model may be a preferred method, but their input parameters are often difficult to measure or obtain (Karpouzli, 2003). For ADS40 data, acquired over the Rheinau test site at low altitude (e.g. 2400 m a. ground) and with clear sky conditions, the empirical line correction approach may be a fast and suitable option (Ferrier, 1995; Smith & Milton, 1999). The empirical line approach derives an empirical relationship from ground measurements of reflectance at selected targets and the at sensor reflectances. If the targets are spectrally stable over time, the ground measurements of one date may be applicable to another acquisition date, at least in the same region.

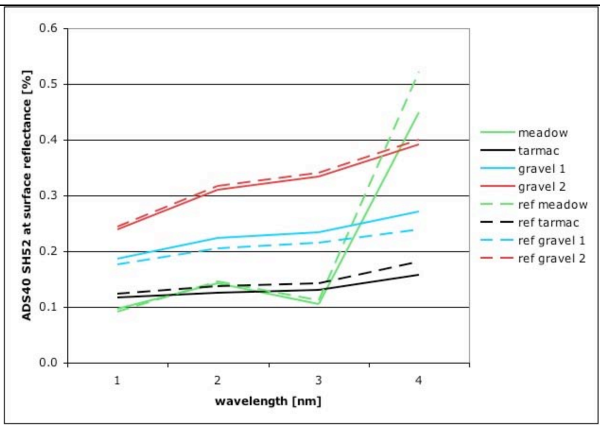


wavelength [nm]	meadow	tarmac	gravel 1	gravel 2	pond
470	6.0%	5.9%	-6.5%	2.2%	-43.4%
560	3.2%	9.3%	-8.4%	2.3%	-32.5%
635	11.6%	10.0%	-8.6%	2.2%	-35.9%
860	-6.1%	12.5%	-10.2%	1.8%	-78.0%

Figure 4. Comparison of ADS40 and ASD-spectrometer at surface reflectance of reference targets, ADS40 sensor head SH52, September 2007, empirical line corrected with ASD targets ‚tarmac', ‚gravel 1' and ‚gravel 2' of September 2007

The day of the SH52 data acquisition in September, five calibration targets were measured with the ADS field spectrometer (Fig.3), where 'tarmac', 'gravel 1' and 'gravel 2'

are assumed to be spectrally stable. The 'meadow ' target was measured as control target, whereas the 'pond' target was expected to be very inhomogeneous due to the water fountain and the low water level in the pond. The continuous ASD reflectance spectra per target were folded spectrally onto the spectral band characteristics of the four ADS40 bands.
Based on the relationship between the folded calibration target reflectances of 'tarmac', 'gravel 1' and 'gravel 2' and the SH52 data from the same date, the at-sensor radiances of ADS40 SH52 were corrected to at-surface reflectances (Fig. 4). The comparison in (Fig. 4) of ADS and SH52 at-surface reflectances of the three calibration targets shows the best fit of the empirical relationship. The correction was very successful for the independent reference target 'meadow', where little difference in surface reflectances occurs. The reflectances in the 'pond' target differ substantially due to water turbidity (fountain was temporarily switched on) and water level variations.
In a second step, the empirical correction of the ADS40 SH40 data of July 2007 was carried out, applying the identical three calibration targets 'tarmac', 'gravel 1' and 'gravel 2' previously applied to the SH52 data and measured in September 2007. This approach requires the assumption of spectrally stable calibration targets over time.



wavelength [nm]	meadow	tarmac	gravel 1	gravel 2
470	-5.1%	5.6%	-6.1%	2.1%
560	1.9%	8.8%	-8.0%	2.2%
635	6.5%	9.1%	-8.0%	2.0%
860	16.2%	15.2%	-12.0%	2.2%

Figure 5. Comparison of ADS40 and ASD-spectrometer at surface reflectance of reference targets, ADS40 sensor head SH40, July 2007, empirical line corrected with ASD targets ‚tarmac', ‚gravel 1' and ‚gravel 2' of September 2007

(Fig. 5) demonstrates the applicability of the September calibration targets to the July dataset of ADS40 SH40. The 'tarmac', 'gravel 1' and 'gravel 2' reference targets allow for a good empirical fit with little, somewhat higher variations in the longer wavelength region. The three calibration targets appear to be spectrally stable. The independent meadow target differs by 16.2% in the nir band. This can be explained by the differing vegetation activity and state between July (SH40 reflectances) and September (ASD calibration reflectances).

The application of the empirical line calibration to ADS40 data is fast, simple and reliable. Tarmac and gravel calibration targets are spectrally stable and applicable to multidate ADS40 scenes. Further investigations have shown, that tarmac is even superior to gravel.

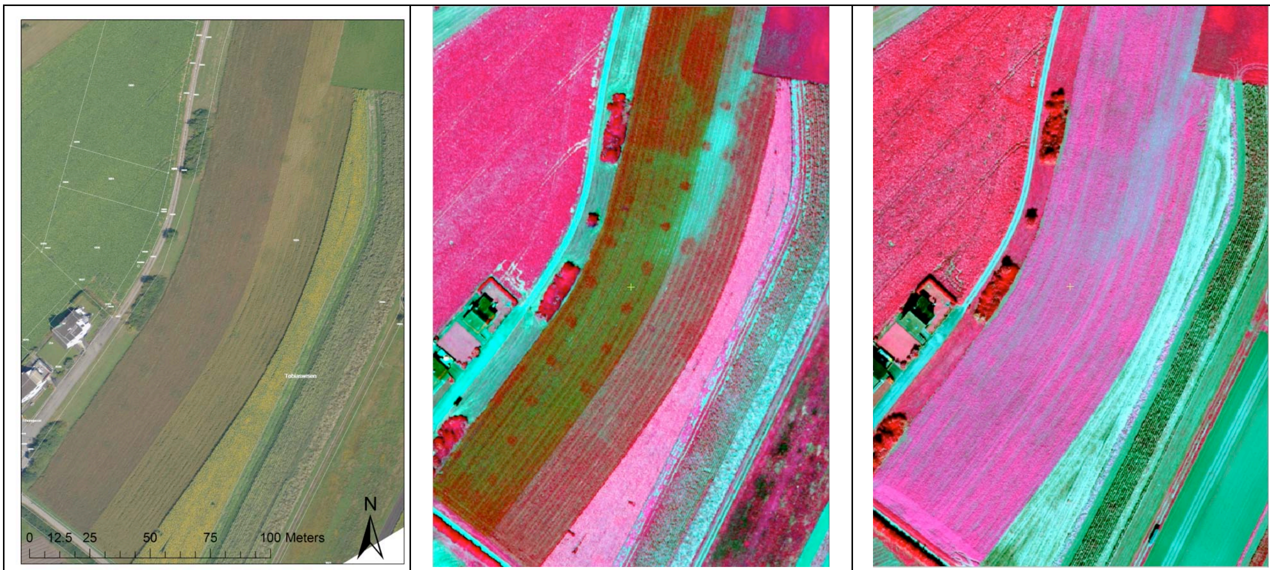
5. ARCHAEOLOGICAL INTERPRETATION

The archaeological interpretation of remote sensing data, such as aerial photographs or digital airborne scanner data, is a subjective process and in most cases a profound expert knowledge is expected. The interpreter has to rely on many natural and man-made features in the images which refer to ancient and recent settlements or civilisation signs. Cultural remains may cause faint lines and colour changes at the topsoil or the covering vegetation, which are detectable from the air but invisible on the ground. The aerial archaeologists refer to these as crop, soil, and shadow marks.
Crop marks are variations in crop height, colour, or vigor when crops or natural vegetation grows over buried cultural remains. Crop or more general vegetation over refilled ancient cavities and pit holes, is more vigorous, greener and often taller than the surrounding plants, due to more moisture availability and better root growth. This effect is called a positive crop mark. The opposite are negative crop marks, where the vegetation is less vigorous due to lesser soil depth, equals moisture, and shows water stress symptoms.
Differences in plant height, as well as elevation variations by hidden archaeological objects, excavations and landfills are detectable by shadow marks. Shadow marks are more pronounced in aerial image data acquired the dawn ore near sundown with low illumination angles.
Variations of the topsoil in humidity, materials or treatment may be discovered from air. The inferences drawn from these so called soil marks can be applied for example to ancient roads, river beds, filled ditches and cavities.
The comparison of the information contents of ADS40 data and traditional aerial photographs for archaeological prospection is one of the objectives of this study. In order to get the best archaeological and interpretation expert knowledge as possible, the ADS40 SH40 and SH52 data and the true-colour aerial photos were interpreted together with specialists of the Archaeological service of the Canton of Zurich, Switzerland. The interpretation was made by a traditional analogue method on a computer screen in a dedicated GIS environment for archaeology. For interpretation true-colour (red-green-blue) and false-colour (nir-red-green) of both, the ADS40 datasets of July (SH40) and September (SH52) 2007, were used. Due to the lacking nir band in nadir direction in the SH40 data, the forward looking nadir band of SH40 was used for the false-colour composite. The inevitable geometric variances by the oblique viewing geometry of the nir band is almost neglectable in flat crops and meadows, where archaeological marks are expected. The different archaeological interpretations were finally compared on a qualitative level.

6. RESULTS

The Benedictine monks of the Rheinau Abbey planted their gardens on the Rheinau peninsula, north of the island of the abbey. The garden is situated in an area of former settlements and harbour facilities. Even after the commanded closure of the abbey in 1862 and its conversion to a hospital, the garden was maintained for a long time and finally leveled and converted to agricultural area some decades ago. The garden area is shown in (Fig. 6) in a true-colour photograph (Fig. 6a) and a false-colour ADS40 SH40 composite (Fig. 6b) of July 2007. The SH52 false-colour composite of September's SH52 acquisition is shown in (Fig. 6c). The brownish, dark field plot of the aerial photo shows in July a bare soil of a harvested crop plot and in September growing intermediate vegetation. Noticeable rounded crop and/or soil marks are clearly visible in the July data, to a lesser extent in the September data.

The archaeological image interpretation of the July photograph and SH40 data of the area (Fig.7a, 7b) reveals elements of the ancient garden, e.g. former positions of trees in an avenue (green), individual cavities (red) assumed to originate from ancient houses and filled-up holes of historic terrain withdrawals (blue). The entire region is under archaeological survey since many years. A lot of traditional aerial, oblique photographs in black and white, true-colour and false-colour have been acquired and interpreted. The totality of currently all detected archaeological structures in the area of the ancient garden is showed in (Fig. 7c). The aerial photo and SH40 data of July have a similar information content regarding archaeological structures. The SH40 data allow for the detection of even some more individual cavities.

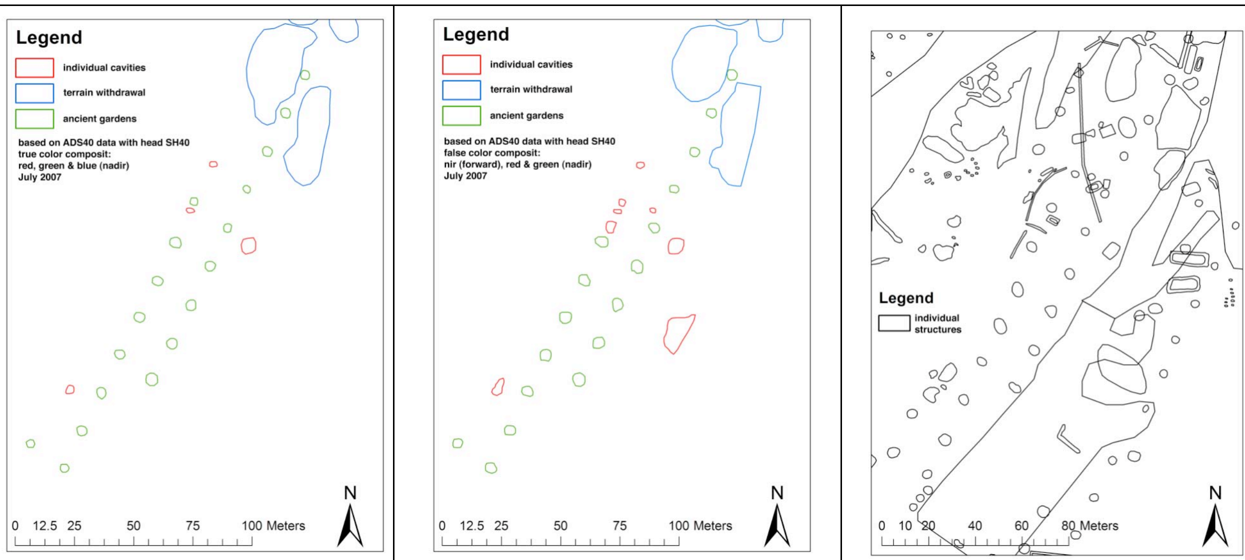


a) aerial oblique true-colour photo July 2007

b) ADS40 with head SH40 – false-colour composite: nir (forward), red & green (nadir) - July 2007

c) ADS40 with head SH52 – false-colour composite: nir, red & green (nadir) - September 2007

Figure 6. The ancient gardens of the Rheinau Benedictine Abbey



a) data base: aerial oblique true-colour photo July 2007

b) data base: ADS40 with head SH40 – false-colour composite: nir (forward), red & green (nadir) - July 2007

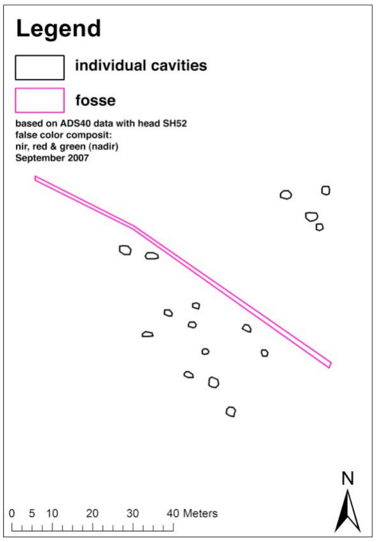
c) data base: B&W, true- and false-colour oblique aerial photographs from several dates

Figure 7. Interpretation of archaeological structures in the ancient gardens of the Rheinau Benedictine Abbey

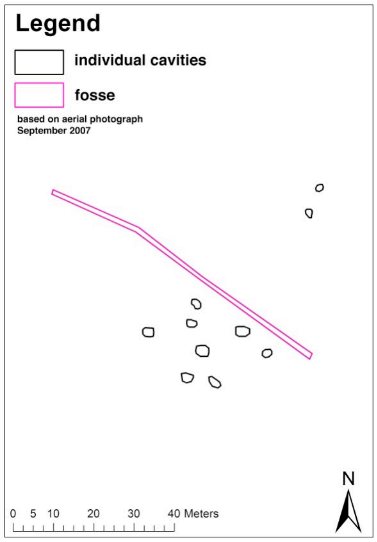
The interpretation of the RGB composite of the SH40 data (not illustrated) shows quite comparable result. The archaeological marks are identified primarily as soil effects and not vegetation variability, where the latter would best be identified in the nir band. The dominance of soil effects is proven, looking at the September SH52 data, where the bare soil is covered by a tiny vegetation cover. The cavities and filled-up holes are almost invisible. Additionally, the addressed archaeological structures are not identified by their shadow effects, e.g. shadow marks. The optimized oblique acquisition geometry of the aerial photographs is in this case not superior to the nadir looking ADS40 data, flown in north-south direction.

Nevertheless, many of the potential archaeological structures (Fig. 7c) in the area of the ancient garden are not visible in the monotemporal acquisition due to heterogeneous vegetation cover, humidity, viewing geometry and acquisition season and daytime. Continuous observations over a multiyear period is necessary for both ADS40 and aerial photographs.

a) ADS40 with head SH52 – false-colour composite: nir, red & green (nadir) - September 2007



b) data base: ADS40 with head SH52 – false-colour composite: nir, red & green (nadir) - September 2007



c) data base: aerial oblique true-colour photo September 2007

Figure 8. Interpretation of a historic fosse and cavities, north of the ancient gardens of the Rheinau Benedictine Abbey

An example for detected historic structures by typical vegetation marks is shown in Figure 8. The structures are best visible in a false-colour composite of the SH52 data in September 2007 (Fig.8a).

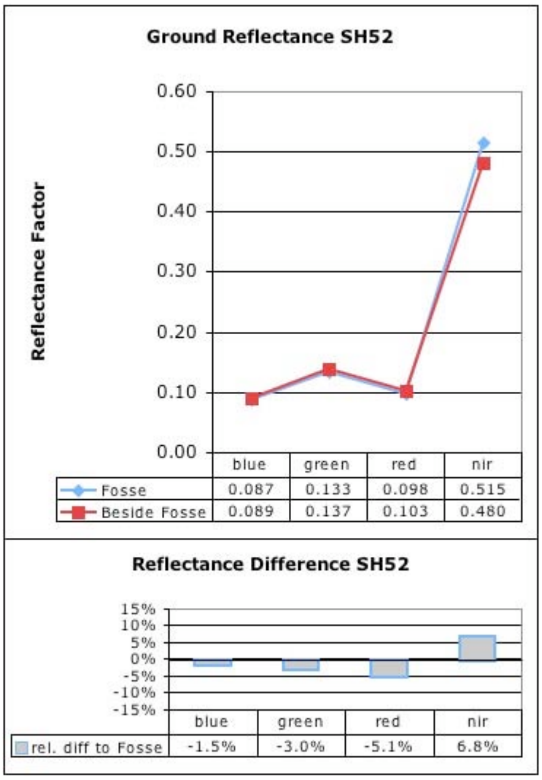


Figure 9. ADS40 SH52 ground reflectances of detected fosses compared to the surroundings

The archaeological image interpretation identified a refilled fosse, surrounded by several individual cavities (Fig. 8b). The detectability of the structures in an oblique true-colour photograph was equal to the false-colour SH52 composite (Fig. 8c).

A detailed view of the reflectances above and beside the fosse (Fig.9), measured by the SH52 sensor head, shows a target reflectance difference in the nir (6.8%) and red band (-5.1%). This is typical for a crop-type mark, which is based on increased vegetation activity over the refilled fosse with its better storage capability for soil water. The vegetation-layer above the fosse is higher than the surroundings and results additional in shadow marks, which is the driving factor for the detectability of the fosse in the oblique aerial true-colour photograph (Fig. 8c).

7. DISCUSSION AND CONCLUSIONS

The empirical line correction approach for ADS40 data was successful. We were able to radiometrically correct a chronological earlier data set, acquired by a differing sensor head, with spectrally stable reference targets of a single date. Further on the excellent state of the manufactor based sensor calibration of both ADS40 sensor heads.

The amount of detectable archaeological structures in the aerial photographs and the ADS40 data is pleasant on the background of not having ideal conditions for data acquisition for aerial archaeology: First, the summer 2007 was very dry in the region and hampered the formation of intense crop and soil marks. Second, the perfect conditions to develop intense detectable vegetation marks is during the crop growing season in May to June before the maturity phase. The selection of an ideal acquisition point and a multi-annual approach are prerequisite for a successful and comprehensive archaeological aerial survey by ADS40 or aerial photographs. The nationwide survey of Switzerland with ADS40 by swisstopo in a three year interval is

an excellent and economic chance for all archaeological offices to prospect for even remote sites.
ADS40 data is shown to have a big potential for archaeological prospection. The simultaneous acquisition in four high resolved spectral bands (including the nir band) allows for search after crop and soil marks in one single data set. The success rate for the detection of archaeological structures is equal or even better with ADS40 data than with (oblique) aerial photographs. This relates also to the high radiometric performance of ADS40 (12 bit), which allows the detection of detailed surface variations even in shadowed areas.
Further investigations to detect archaeological structures digitally and automatically in multitemporal ADS40 data are going on.

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