

Looking through Black-Tinted Glasses – A Remotely Controlled Infrared Eye in the Sky

Geert Verhoeven,¹ Jo Loenders

¹ Research Assistant of the Fund for Scientific Research - Flanders (FWO), Department of Archaeology and Ancient History of Europe, Blandijnberg 2, B-9000 Ghent, Belgium

Introduction

Since more than one hundred years, oblique aerial photography has proven to be an extremely valuable tool for (landscape) archaeologists. However, the vast majority of the pictures taken only record the reflected visible portion of the electromagnetic spectrum produced by the sun, whereas an infrared view can often reveal more information when compared to this “traditional” imagery. Both the technique and use of infrared photography are explored within the multidisciplinary survey project entitled Potenza Valley Survey (PVS – regione Marche, Italy) by archaeologists of Ghent University (Belgium). To acquire data, a newly build apparatus allows the researchers from the PVS to take both “regular” and infrared pictures of archaeological interesting landscapes and *loci* in Italy as well as in Belgium. Moreover, this construction will also prove useful in mapping excavations.

Potenza Valley Survey

In January 2000, the Departments of Archaeology and Geography at Ghent University (Belgium) initiated a geo-archaeological survey project in Central Italy, titled “The Potenza Valley Survey. From Acculturation to Social Complexity in Antiquity: A Regional Geo-Archaeological and Historical Approach”. The main aim of the project was (and still is) to reconstruct both the archaeological and geographical landscapes along the Potenza river, which flows over its 80 km long course from the Umbria-Marches Apennines through a wide and fertile Apennine foothill landscape, before it ultimately runs into the generally flat Adriatic coastline zone (figure 1). Although it was already important in Prehistory, the Potenza river valley became one of the most commercial routes of the Central Italian Protohistory and even in later periods the valley remained an important corridor for political, economical and cultural contacts between the

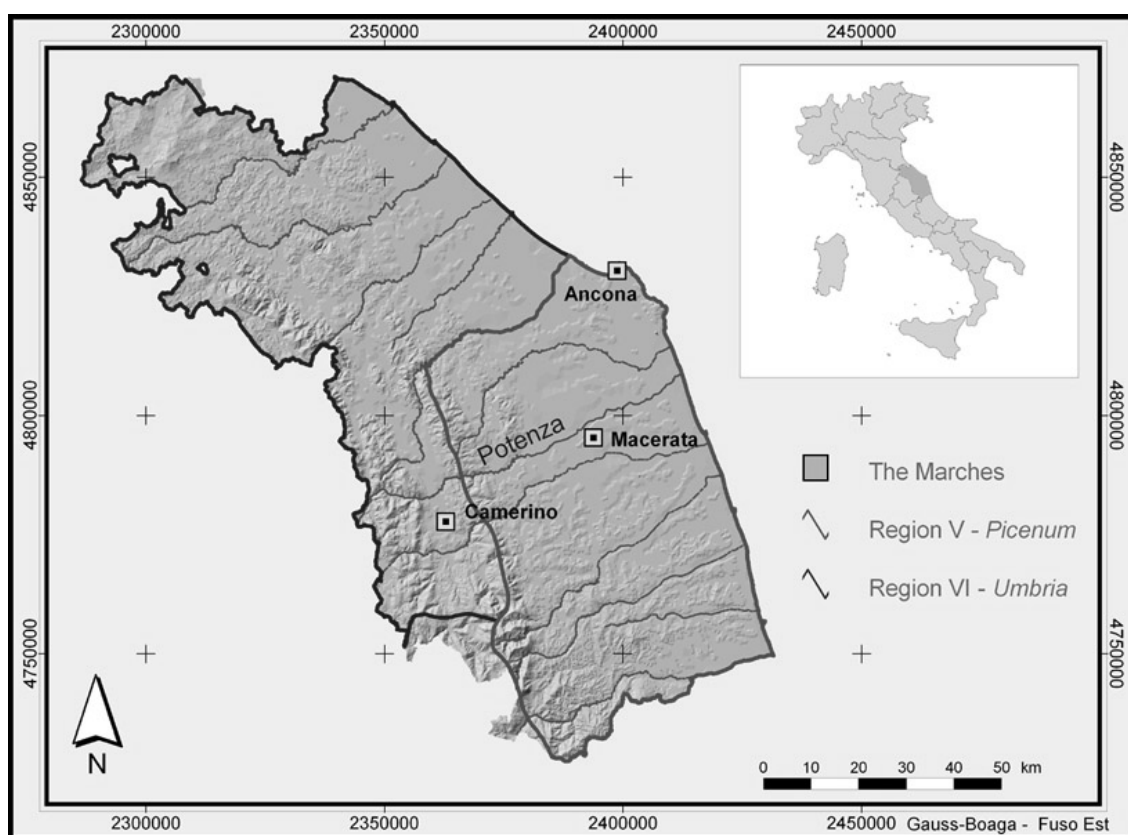


Figure 1 Location of the Potenza valley

Tyrrhenian and the Adriatic coast. In Roman times, several cities developed in or near the valley floor and even a southern branch of the *Via Flaminia* passed through it. In the subsequent period, the area remained of importance as it formed the contact zone between Longobards and Byzantines.

To fulfil the initially outlined goals, three specific sample zones, systematically spaced around the Potenza river, are (or were) subjected to major survey techniques: aerial, field, geomorphological, geophysical and a historical survey. The aerial survey comprises the collecting of all (if possible) remotely taken imagery ever taken above the valley. Besides this passive part, taking oblique photographs from a low flying aircraft is also executed. Till now, this has been done in a very thorough way: on the one hand, different flights were made in different seasons; on the other hand, pictures were taken of the whole valley with a specific interest in the three sample zones.

Although started with an analogue small format Single Lens Reflex (SLR) camera, a digital SLR camera (Canon EOS 300D) was bought in 2004 to speed up the workflow. Both systems yielded photographs which captured the visible portion of the electromagnetic spectrum. In 2005, the idea was born to also partly incorporate the infrared radiation.

Electromagnetic Spectrum

Centuries ago, the highly-gifted Englishman Isaac Newton (1642–1727) discovered that white sunlight could be divided into the colours of the rainbow (red, orange, yellow, green, blue, indigo and violet) using a simple prism. Such a range of colours is called a *spectrum* (the Latin word for “apparition”). Newton also put forward that light consisted of tiny particles, every individual particle too small to be seen. This vision was claimed to be wrong by the Dutch physicist Christiaan Huygens (1629–1695), who declared light travelled in the form of waves. Experiments in the early nineteenth century confirmed this wavelike nature of light.

A major next step was taken by the Scottish mathematician and physicist James Clerk Maxwell (1831–1879), who mathematically accomplished to describe all basic properties of electricity and magnetism in only four equations. Both electrical and magnetic fields were discovered to have an intimate relationship, being part of one phenomenon called electromagnetism. Maxwell stated that visible light was in fact an electromagnetic wave. It comprises two oscillating electric and magnetic fields perpendicular to each other as well as perpendicular to the direction of propagation (figure 2), travelling at about 300 000 km/s (more specifically 299 792,458 km/s or 186 282,397 mi/s).

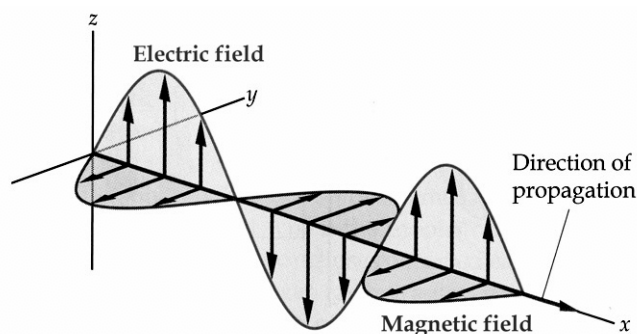


Figure 2 An electromagnetic wave
(adapted from Walker 2004, fig. 25-3)

When light travels in air, glass, water or other transparent substances, this speed decreases. Being a wave phenomenon, light can be characterised by the length of its waves, called the wavelength (λ). Because wavelength is mostly expressed in nanometre (nm), visible electromagnetic radiation is defined as all light with wavelengths between approximately 380 nm and 730 nm (figure 3).

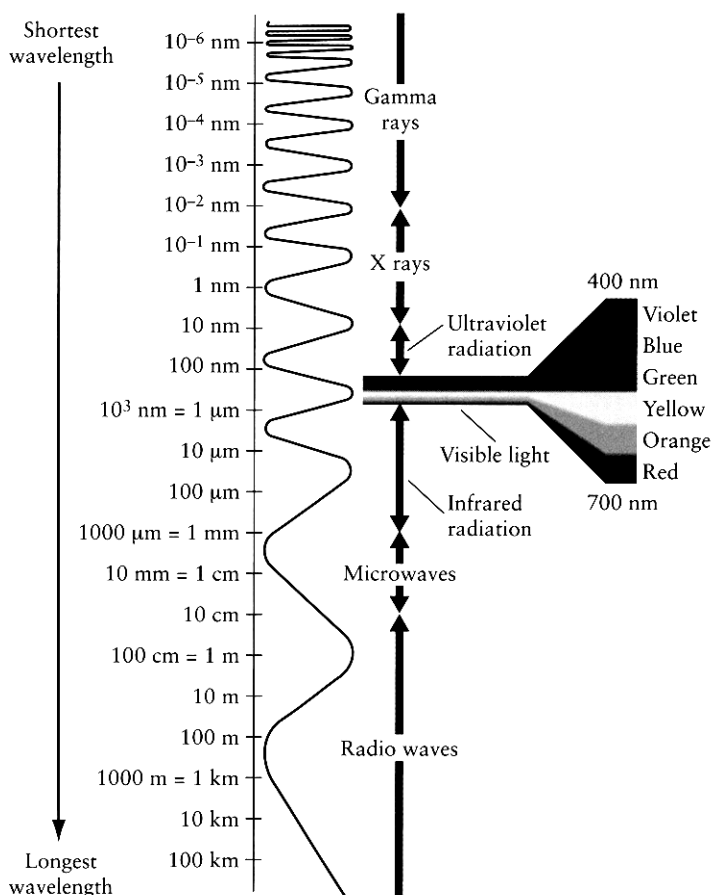


Figure 3 The electromagnetic spectrum
(after Freedman & Kaufmann 2005, fig. 5-7)

In addition to this visual part of electromagnetic radiation, electromagnetic waves also come in forms human eyes are not sensitive to. In fact, the visible light is only one narrow range out of all electromagnetic waves (called the electromagnetic spectrum – see figure 3).

On both sides of the visible spectrum reside bands which do not produce a visual sensation. They all have smaller or larger wavelengths and are given names as gamma rays, X rays, ultraviolet rays, infrared rays, microwaves and radio waves.

A third attribute – besides wavelength and speed – to characterise electromagnetic waves is frequency, which denotes the number of complete waves passing a certain point in one second. Short wavelengths therefore yield high frequencies. Frequency is always expressed in hertz or cycles per second (abbreviated Hz and denoted by ν).

Today, it is known Newton was not wrong after all. One of the key concepts in quantum mechanics is the *wave-particle duality*, meaning light behaves both as waves and as particles. This particle theory was raked up by the German physicist Max Planck (1858-1947), who in 1900 suggested that light must be emitted and absorbed in certain fixed amounts called quanta, rather than continuous quantities. Five years later, Albert Einstein (1879-1955) writes a paper in which he draws upon Planck's quantum idea to explain the photoelectric effect (i.e. the phenomenon in which electrons are ejected from a metal surface when light shines on the metal). Einstein proposed that these light quanta or discrete energy packets were in fact particle-like entities (now called *photons*). Depending on the wavelength of the electromagnetic radiation, the energy of the photons was different. Due to this dual behaviour, electromagnetic radiation can also be seen as a travelling bundle of photons.

When light (no matter if it is visualised as waves or photons) falls onto an object, the object can do three things: transmit, absorb or reflect the light. The latter is the main idea of passive remote sensing: capturing that specific portion of the electromagnetic radiation which is produced by the sun, partly transmitted by the atmosphere and reflected by objects (e.g. plants, humans, bare soil, buildings).

Infrared Photography

- What?

Besides the small range of the visible spectrum, other wavelengths can be recorded by either electronic sensors or photographic film. However, only a limited portion of electromagnetic radiation can be captured using film. Radio waves for instance will not produce a latent image on the photographic emulsion, but infrared and ultraviolet waves can. The complete range of wavelengths that is able to expose film is denoted the *photographic*

spectrum. On both sides of the visible spectrum, wavelengths do exist that still fall in this photographic spectrum. Wavelengths shorter – and hence more energetic photons – than blue visible light are called ultraviolet (UV) rays, while infrared (IR) radiation resides on the other side of the visible spectrum. Therefore, these waves have longer wavelengths (lower frequencies) than light from the visual spectrum. Here, only infrared radiation is considered.

The width of the infrared band is exceptionally wide, spanning three orders of magnitude and comprising wavelengths between 730 nm (the edge of the visible spectrum) and 1 mm. Although the limits are often differently used, the infrared radiation can be divided into five different zones.

1. Near InfraRed (NIR) from 0,73 μm – 1,4 μm (micrometer);
2. Short Wavelength InfraRed (SWIR) from 1,4 μm – 3 μm ;
3. Mid Wavelength InfraRed (MWIR) from 3 μm – 8 μm ;
4. Long Wavelength InfraRed (LWIR) from 8 μm – 15 μm ;
5. Far InfraRed (FIR) from 15 μm to 1000 μm (= 1 mm).

Often, only near (0,73 μm – 5 μm), mid (5 μm – 30 μm) and long (30 μm – 1000 μm) infrared are used. The mid and far IR bands are known as the thermal bands. It is even often said that beyond 1350 nm, the infrared radiation is thermal radiation. Imaging these long wavelengths (called *thermography* or thermal imaging) is not possible with conventional IR film and digital cameras, but only with special non-photographic equipment.

Consequently, just the spectral range from 730 nm to 1350 nm is important for photographic purposes (although the region most accessible for conventional films is limited to around 925 nm, while digital cameras often react to wavelengths of up to 1000 nm and even more). Therefore, photographic emulsions are unable to capture so-called “heat-images” (i.e. infrared radiation emitted by objects). What they record is the portion of near infrared radiation that is produced by the sun and reflected by objects in specific amounts.

- Why?

The reason for capturing this radiation is rather easy to explain. For the human visual system, real-world objects have a certain colour which corresponds to the visible light that is reflected by the object. If light falls on a ripe tomato, the red part of the visible spectrum will be reflected most; hence, the tomato will be perceived red. This principle also holds for infrared recording. Objects reflect or absorb infrared radiation in certain amounts. As an example, consider green vegetation (e.g. grass, a tree, foliage) which reflects the green part of the visible spectrum due to the chlorophyll – a green pigment –

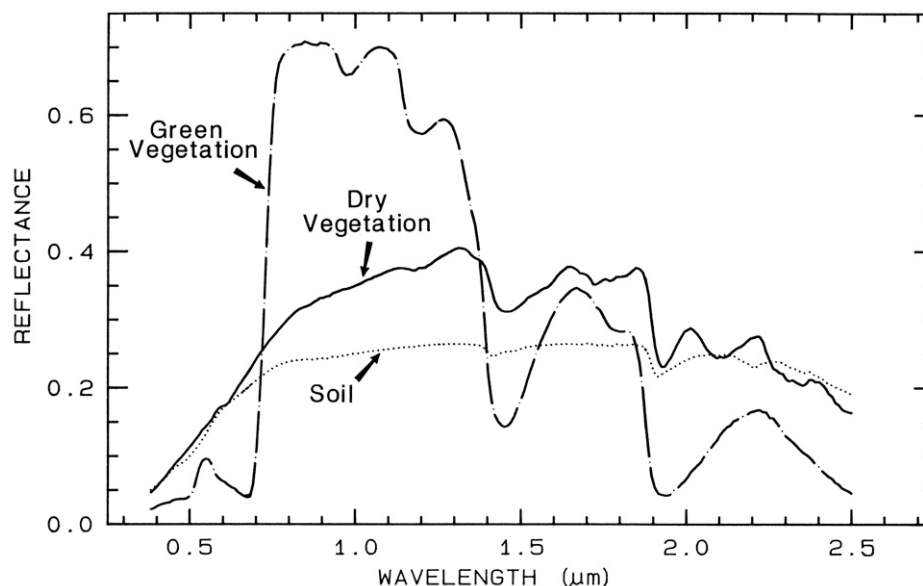


Figure 4 Reflectance spectra of photosynthetic (green) vegetation, non-photosynthetic (dry) vegetation and a soil (after Clark 1999, fig. 1.18)

inside. Additionally, chlorophyll also strongly reflects invisible near infrared light. When imaged on colour-infrared film, healthy growing vegetation will appear bright red due to the high amounts of chlorophyll. On the other hand, chlorophyll quantities in stressed, unhealthy or dead vegetation are much lower, leading to less near infrared light being reflected. Hence, these plants will appear light red or darker in the photograph. Due to the fact that chlorophyll reflects around 50% of the near infrared radiation as opposed to around 15% of the visible green component of light, plant stress (e.g. grass growing on a buried wall) is much easier to discern in these non-visible wavelengths (clearly illustrated by the spectral reflectance curve in figure 4). This principle allows aerial survey to monitor the condition of vegetation.

- Equipment

To obtain the photographs, Kodak Ektachrome EIR Infrared film is used in this project. The emulsion, which is sensitive to wavelengths between 380 nm and 900 nm, is a so-called false-colour slide film, meaning the images are created from a wider range spectrum than the visible light and finally remapped into the visual spectrum range. This way, a false-colour image is created because the invisible near infrared wavelengths are displayed as red by the film, whereas red and green objects are depicted as green and blue respectively.

The film is manually set to ISO 200, which is necessitated by the fact that exposure meters are not sensitive to infrared (and hence infrared film does not have a fixed ISO value). Therefore, shooting and evaluating a lot of test strips is the only way to determine the right exposure when photographing infrared.

Besides film, filters can be used to only capture a specific portion of the visible and infrared radiation. Whereas most infrared photography is performed using a visible light filter (often a yellow or red filter), this project applies an infrared filter (B&W 093), delivering a pure infrared picture (as the glass of the filter is completely opaque to all visible wavelengths). By this approach, it is hoped to detect stress in plants growing on archaeological sites much better, as the image will not be “disturbed” by the visible wavelengths. On the other hand, using an infrared filter also has a major drawback: the photographer can not see through them, meaning framing and focusing must be done before screwing the filter on the lens. Moreover, shutter speed can become rather long, meaning the camera must be mounted onto a stable platform to not end up with fuzzy images.

Helikite Aerial Photography

To deal with all previously mentioned difficulties, a stable, easily maintainable and remotely controllable construction had to be created. Moreover, as the archaeological crew from Ghent University goes to Italy only for some limited periods, the apparatus must work in most weather circumstances and be easily transportable. In this section, all components which are part of the finally assembled system will be described separately.

- Helikite

This camera-lifting construction, maybe the most important piece of the whole system, joins a helium balloon with a kite (figure 5). This unique design, patented by Allsopp Helikites Ltd combines the best properties of both objects. The balloon enables a helikite to take off in windless weather conditions – something a kite is unable to do –, whereas the kite components play

two important roles in case there is wind: they lift the helikite higher up in the air, while additionally stabilising this lighter-than-air construction. Consequently, they overcome the knocking down of the helikite in windy conditions, a major drawback of all normal balloons. Moreover, the more wind, the stronger the lift (with a maximum threshold depending on the helikite's size).



Figure 5 *Inflating the helikite*

In this respect, the Allsopp helikite is both smaller and more versatile than comparable lighter-than-air constructions, operates in stronger winds than traditional blimps and – by the additional lift through its wings – supports more payload for its size when compared to ordinary aerostats.

Due to the fact that it can be used in adverse weather, it is also more flexible than a remotely controlled (R/C) helicopter. Additionally, R/C helicopters can only hang stable for a while when controlled by an experienced user (and there still is the vibration problem). Although the helikite is not cheap (£ 2100 or around € 3100 for a 7 m³ model), its maintenance cost is low and very expensive crashes are out of the question (which is the reason why R/C helicopters ultimately cost twice the amount of money they are sold for).

The helikite used is – as mentioned – a 7 m³ model, enabling a lift of around 3,5 kg in windless conditions, increasing to even 10 kg in 25 km/h wind (for all prices and facts about the different products, please check www.allsoophelikites.com). By analogy with KAP – which means Aerial Photography by means of a Kite – this type of photography is inaugurated HAP or Helikite Aerial Photography.

- Tether

To securely fly the helikite, a Dyneema tether is used (as is also recommended by Allsopp Helikites Ltd). These tethers combine a small mass with a large breaking strain (in this case 270 kg).

- Picavet system

Named after its French inventor (Pierre L. Picavet) who first described this suspension in 1912, the Picavet system is a construction which allows for dampened suspension (figure 6). It is hanging below the dyneema line by means of two pulleys (which are several meters apart) and must stop the camera from spinning around when manoeuvring with the helikite on the one hand, as well as absorbing vibrations created by the wind on the other. As can be seen from figure 6, the Picavet suspension involves a rigid cross with each of the four ends connected to two attachments on the kite line. The small line which provides these connections is a continuous looping string. Lastly, the crossing two innermost cables are constrained with a ring. The result is a simple, very lightweight system for self-levelling and securing the camera-supporting frame or cradle. (Both the cradle and a suspension system are denoted as camera rig.)

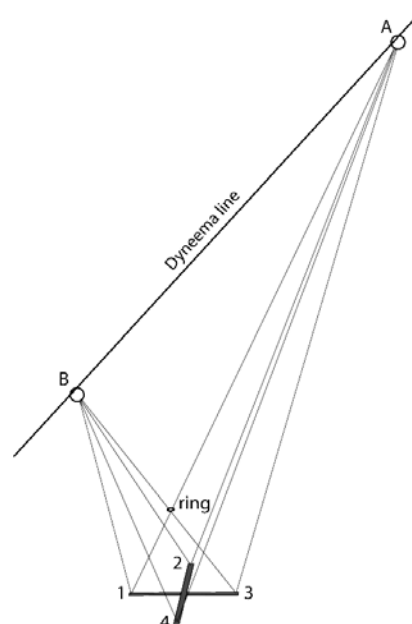


Figure 6 *The Picavet suspension*

- Cradle

The sturdy cradle, devised and built by J. Loenders within the framework of his master's thesis, was specifically designed to allow camera rotation around all three X-, Y- and Z-axes (figure 7). Its four carbon legs allow the construction to stand and take-off independently and protect the camera in case of a tough landing. Moreover, precisely lasered and bended solid aluminium frame profiles allow for extremely fluid rotations, the latter all directed by a 35 Mhz remote control unit which commands three small servo motors. On the frame, an analogue 35 mm SLR camera (Nikon F70) is mounted. By adapting the camera's remote shutter release, completely automatic focusing is made possible as well as ultimately releasing the shutter to take the photograph (both actions are also controlled remotely).



Figure 7 *The cradle with mounted camera*

- Monitor – video live link

Framing the shot correctly is enabled by the Pro X2 (www.hicam.com.au/pro_x2.htm), a very handy video live link system. Using a tiny 4,8 V Hi Cam EO5-380 CCD camera mounted onto the camera's eyepiece, the image that will be captured by the camera is remotely sent to a ground-based monitor, where an archaeologist can decide whether or not to take the image. Thanks to its maximum compactness and minimum weight, the Pro X2 system is ideal for R/C aerial photography. Moreover, most commercial equipment is not capable of sending images further than 100 m line-of-sight. Due to the 200 mW of output power, this 2,4 GHz transmitter enables to send a signal over about 300 m line-of-sight.

Although humans are incapable of seeing something through the camera when the infrared filter is mounted, the CCD of the little camera allows to 'see through' the infrared filter because digital sensors are sensitive to near infrared. This way, the picture that the analogue film will capture is instantaneously shown on the small (7 in) TFT monitor (figure 8), making the archaeologists on the ground aware of the captured features.

- Fishing reel and rod

One can imagine the tractive force of the helikite when flying even in moderate winds. Using a big game fishing reel and accompanying sea-fishing rod, these forces can be managed reasonably well and, on the other hand, allow the helikite's "pilot" to freely walk around. Fixing a large and solid winch to the ground could be more convenient to pull down the helikite, but severely restricts steering and risks the penetration of archaeological layers (e.g. floors).



Figure 8 *Steering the camera by assistance of the video live link*

Problems and Terra Incognita

When combining all these elements, a complete HAP system is created (figure 9) which almost completely fulfils the initial aims.



Figure 9 *HAP in action*

However, as this is still a prototype and the first tests were only executed in the summer of 2006, it is likely that changes and improvements will have to be made. One of the first issues already encountered was the communication between the helikite pilot and the person taking the photographs. Bad communication will certainly yield bad photographs. Furthermore, as all equipment is battery-driven, spare (and fully charged!) batteries are a necessity when working in remote areas. Furthermore, a good pair of gloves is essential as well,

because fast running tether can burn or severely cut exposed skin when performing KAP or HAP. It also still remains unsure whether or not the carbon legs will have a major influence on the rig's stability when flying in high winds. Finally, it must be admitted that the cost of helium was underestimated. As helium comes with a rather high price tag, filling a helikite of 7 m³ time after time is very detrimental for the project's budget. Consequently, a large trailer which can store the whole system – partly or completely inflated – will be bought.

Archaeological HAP Applications

It must be obvious that HAP will not only be used to take infrared photographs.¹ For instance, the system will also be used as a research instrument to look at the information embedded in the ultraviolet spectrum. Moreover, it allows for detailed photography of archaeological *loci* – something which is more (or too) difficult to achieve when photographing from an aircraft at 300 m altitude. In close relation with the previous application, it is hoped to put HAP into action on excavations (figure 10). By taking two overlapping images from a different point of view (i.e. a stereopair) of the excavation area, photogrammetric software allows to extract an orthophoto (i.e. a completely distortion free and true-to-scale photograph) on which accurate measurements can be carried out. It is hoped that this approach will turn out to be a possible solution for the always occurring accuracy, precision, cost and time issues concerning archaeological excavation mapping.



Figure 10 HAP on an excavation

To even further increase the flexibility of acquiring aerial imagery, a digital camera will be implemented into the system. Removing its internal IR cut filter (the so-called *hot mirror*) to make the sensor capture infrared radiation, will allow to directly take near infrared photographs, hence removing the buying, processing and scanning stages as well as the cost of purchasing and processing the film. When taking two individual overlapping images

will prove to be unpractical, a stereo rig using two cameras can also be considered. This way, stereopairs would be created automatically without having to manoeuvre the helikite.

What the future will bring for HAP may be uncertain, but it can be stated that from now on HAP will allow the Ghent University researchers to look at archaeology through black-tinted glasses.

Acknowledgements

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¹ Due to the fact that the film development was not finished at the moment of writing, no infrared pictures could be included in this article.