TRANSACTIONS OF THE KANSAS ACADEMY OF SCIENCE
Vol. 112, no. 1/2
p. 31-39 (2009)

Challenge of infrared kite aerial photography: A digital update

JAMES S. ABER[1,3], SUSAN W. ABER[1], LIDA BUSTER[1], WILLIAM E. JENSEN[2], AND RICHARD L. SLEEZER[1]

1. Earth Science Department, Emporia State University, Emporia, Kansas 66801
2. Department of Biological Sciences, Emporia State University, Emporia, Kansas 66801
3. Corresponding author: jaber@emporia.edu

Kite aerial photography (KAP) is a means to acquire large-scale, highly detailed imagery for various environmental applications. Previous color-infrared KAP was developed for film-based cameras, but is now effectively obsolete. The authors have built a KAP rig and field tested a digital color-infrared camera, the Tetracam ADC, which produces results that are generally comparable with color-infrared film photography. Field testing was conducted at the Cheyenne Bottoms Preserve of The Nature Conservancy in central Kansas. The resulting images are high-contrast photographs that depict emergent vegetation in bright red-pink colors and show water bodies nearly black, as would be expected in color-infrared imagery. Color-visible digital cameras produce better apparent spatial resolution, whereas the Tetracam ADC camera provides an extended spectral range into the near-infrared. For detailed environmental field investigations involving kite aerial photography, a combination of color-visible and color-infrared cameras is recommended for improved results overall.

Keywords: infrared, digital, kite, aerial photography, wetlands, Cheyenne Bottoms, Kansas.

INTRODUCTION

Kite aerial photography (KAP) is a type of small-format aerial photography, which is based on compact film or digital cameras flown on various manned or unmanned platforms (Warner, Graham and Read 1996; Bauer et al. 1997). KAP typically operates less than 150 m above the ground, and pictures can be taken in vertical or oblique vantages in any direction relative to the ground target and sun position (Fig. 1). Resulting images have large scale and high spatial resolution (2-5 cm) that depict ground objects in surprising clarity. The method is especially well suited for detailed investigations of small study sites comprising a few hectares for diverse types of natural or cultural features.

Two of us (JSA and SWA) have elaborated kite aerial photography for various environmental applications (e.g. Aber et al. 1999; Aber and Aber 2001; Aber et al. 2002; Aber, Eberts and Aber 2005). These studies typically involve vegetation, soils, and water bodies, for which color-infrared aerial photography is particularly valuable as a survey, mapping, and monitoring tool (Mace et al. 1997; Murtha et al. 1997). The near-infrared portion of the spectrum highlights active vegetation and water bodies quite distinctly (Jensen 2007).

We earlier developed film-based color-infrared kite aerial photography to exploit this potential for environmental investigations (Aber, Aber and Leffler 2001). This technique was based on color-infrared, 35-mm, slide film and a conventional SLR camera with a yellow filter. However, this method has become effectively obsolete for two reasons. First, Kodak Ektachrome EIR was the only color-infrared film available in the United States, but it is now quite expensive and difficult to obtain.

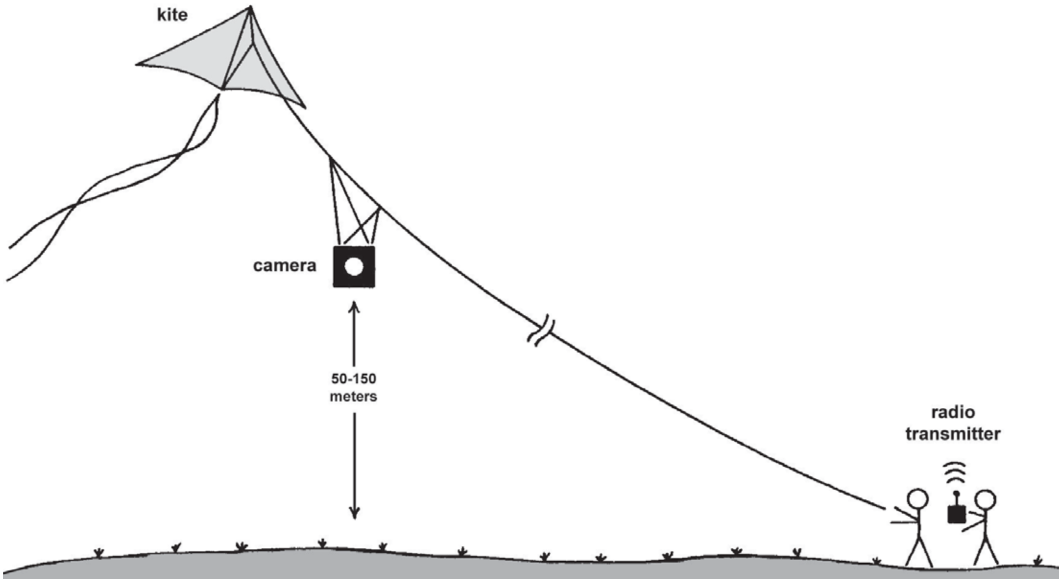


Figure 1. Cartoon showing setup for kite aerial photography (KAP). A radio transmitter on the ground controls operation of the camera rig. Illustration not to scale. Adapted from Aber, Zupancic and Aber (2003, fig. 1).

Second, developing this film requires special darkroom techniques, and nearly all commercial laboratories have ceased to process this film.

Here we report development of digital color-infrared kite aerial photography and present results of field testing from The Nature Conservancy (TNC) marshes at Cheyenne Bottoms in central Kansas. Color-infrared aerial photography is considered best for identification of vegetated wetlands in many situations, including marshes, swamps and bogs (Tiner 1997).

Tetracam ADC camera and rig

Camera — The primary challenge was to identify a suitable color-infrared digital camera of relatively small size and weight at a cost that could be justified for kite aerial photography. Only one commercial camera is known to the authors to meet these requirements, the Agricultural Digital Camera (ADC) by Tetracam. The camera has the following general characteristics (Tetracam 2008):

- CMOS sensor: 2048 x 1536 pixels (3 MB or 3.2 megapixels).
- Spectral range: 0.52 to 0.92 μm wavelength (green, red and near-infrared).
- Image storage format: proprietary DCM lossless format.
- Memory: removable Compact Flash card.
- Lens: 4.5- to 12-mm CS-mount zoom lens with manual focus and aperture adjustment.
- Filter: permanently mounted long-pass filter behind lens.
- Body: machined aluminum.
- Dimensions: length - 4.8 in (122 mm), height - 3.05 in (77.5 mm), depth including lens - 3.5 in (89 mm).
- Weight without batteries, 12 oz (460 g).
- Power: 8 AA batteries, internal.

The primary applications for this camera are, as the name suggests, agriculture as well as forestry and other studies involving vegetation, soil and water. The camera is designed to be operated on the ground or from manned or unmanned aircraft either by hand or remote control. Its size, shape, weight, and operating characteristics place this camera within the normal range for digital SLR-type cameras. Cost of the camera and lens with educational discount was about $4500.

The first phase of camera operation began on the ground with the camera either hand held or mounted on a tripod for stability. The biggest problem for using this camera routinely proved to be adjusting the lens focus and zoom properly. Considerable trial-and-error testing was necessary to achieve a suitable field of view and focus, which are fixed with locking thumb screws on the lens. The field of view was set to approximate a 40-mm focal length for a standard 35-mm film camera, which produces a slight wide-angle effect. Lens aperture (*f*-stop) is likewise adjusted manually based on lighting conditions. The image file format is proprietary, and special Tetracam software is necessary to process and display the false-color images (Fig. 2).

KAP rig — We built a radio-controlled KAP rig based on a kit and accessories from Leffler (2008). The basic kit had to be modified to accommodate the Tetracam ADC camera; the rig features full control of camera tilt, pan, and shutter button (Fig. 3). The radio receiver and servos are powered by rechargeable nickel-metal-hydrite (NiMH) batteries.

Aside from reliable camera operation, the most important design criterion for building the KAP rig was to minimize weight. In this regard, the greatest single factor is 8 AA batteries in the camera itself. Eight conventional alkaline AA batteries weigh ~185 g, whereas 8 AA lithium batteries are only ~110 g. Thus, replacing alkaline with lithium batteries reduces weight substantially and provides longer-lasting camera power. We rejected rechargeable AA lithium batteries, though, because of lower output (1.2 v) compared with standard batteries (1.5 v). Total weight of the camera, rig, and batteries is just over 1 kg, which is well within the range of other camera rigs we utilize for kite aerial photography. Cost of the rig kit, accessories, batteries, and spare parts was less than $500.

Field testing at Cheyenne Bottoms

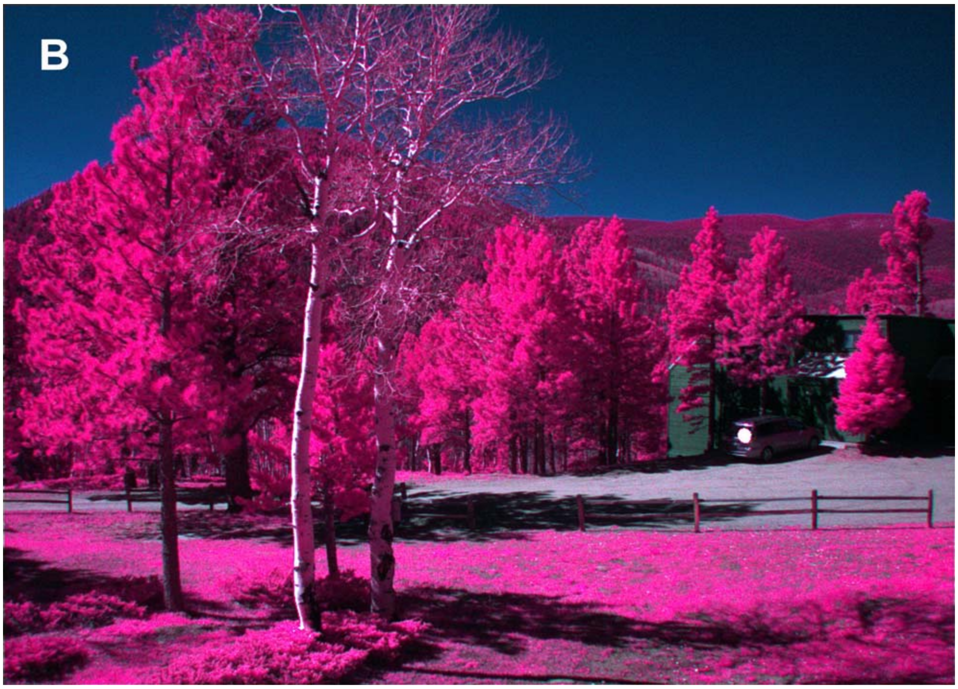
We field tested the Tetracam ADC camera at the Cheyenne Bottoms Preserve of The Nature Conservancy (TNC) in central Kansas, where we have employed small-format aerial photography to monitor marshes for the past several years (Aber et al. 2006). Our long-term goal is to document environmental conditions as consequences of natural climatic events and TNC management practices. Our investigations have focused in particular on frequent changes in water bodies and emergent wetland vegetation.

Kite aerial photography was conducted in the early afternoon on 6 June 2008 under an exceptionally blue, cloudless sky. The marshes were full of water, following heavy May rain and runoff, and emergent wetland vegetation was well developed within and around the study site. A large delta kite (8.2 m²) lifted the camera rig easily on a consistent southerly breeze. Field testing began with close-up shots of the ground crew and launch site (Fig. 4). Oblique pictures were taken in all compass directions from multiple heights. The kite and camera rig flew over open water, so no vertical pictures were attempted. We conducted KAP a second time at the same site on 19 September 2008 using a large Rokkaku kite (3.3 m²), again under nearly ideal weather conditions with high water in the marshes (Fig. 5).

Color-infrared imagery

General characteristics — The Tetracam ADC color-infrared photographs obtained at Cheyenne Bottoms are high-contrast images consisting of bright pink-red-magenta vegetation and dark, almost black water bodies. Other objects, such as the gravel road, are generally intermediate in brightness, although

Figure 2. Ground-based photographs of a sub-alpine forest scene at Cuchara, Colorado. A - color-visible photograph taken in late May with active grass and conifer shrubs and trees (pine and spruce); aspen trees have not leafed out yet. B - Tetracam ADC color-infrared photograph of approximately same scene. Active vegetation appears in pink, red, and magenta colors in this standard false-color format.



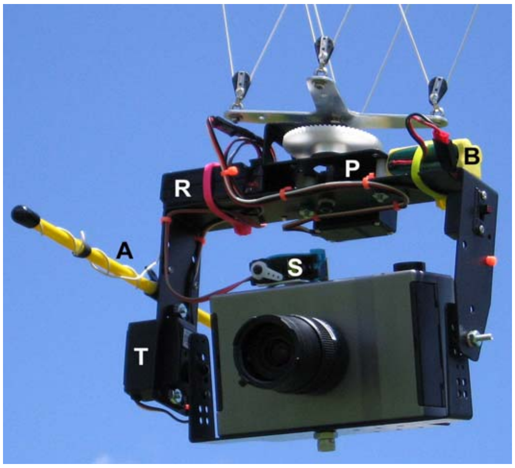


Figure 3. Radio-controlled rig for kite aerial photography with the Tetracam ADC digital, color-infrared camera. R - radio receiver, P - pan servo and gears, B - NiMH battery pack, A - antenna mast, S - shutter miniservo, and T - tilt servo.

direct specular reflections (sun glint) from water bodies and vehicles are quite bright, and shadows are quite dark. In this false-color format, green light is portrayed as blue, red appears as green, and near-infrared radiation is depicted in red (Jensen 2007; Malin 2007). These results are closely comparable with color-infrared film imagery.

Color-infrared photography in either film or digital format blocks blue and near-ultraviolet light from reaching the sensor by use of a long-pass (yellow or orange) filter, which has several effects on the resulting photographs (Finney 2007). Blue is strongly scattered in the atmosphere, so the sky is noticeably darker because blue light is filtered out. In like manner, shadows normally are illuminated mainly by scattered blue light and also appear much darker. The color of water bodies is a function

Figure 4. Upon launching the Tetracam ADC camera rig, the crew took a self portrait. Active vegetation appears in pink and red colors; vegetation is highly reflective for near-infrared, so is much brighter than normal and appears somewhat fuzzy. Note that vehicles and fence poles are sharply defined. Also some artificial fibers and dyes are highly reflective for near-infrared (Finney 2007), as seen in clothing that appears red and pink. June 2008.

Figure 5. High-oblique late summer views over TNC marsh looking toward the northeast. The delta of Deception Creek appears in the left background. A - color-visible image. B - color-infrared image of approximately the same scene. Water strongly absorbs near-infrared energy and so appears quite dark. September 2008.

of scattering of blue and, to a lesser extent, green light and absorption of red and near-infrared; thus, in color-infrared imagery water usually appears dark. However, the water surface may act as a specular mirror in near-infrared as well as visible light; thus, sun glint appears especially strong. All these phenomena are displayed in the Tetracam ADC images.

A potential issue of image sharpness involves focusing the lens. The longer wavelength of near-infrared is refracted slightly differently through the lens compared with visible light (Finney 2007). Thus objects that appear to be in focus in the visible spectrum may not be in sharp focus in near-infrared, even for infinite focal distances. We believe extensive pre-flight, ground testing and lens adjustment minimized this problem. Also an intermediate aperture (*f*-stop) is utilized to force faster shutter speed as another means to minimize image blurring.

In general, visual details appear less sharply defined in the Tetracam ADC images compared with color-visible digital images (see Fig. 5). This may be explained, in part, by the 3.2 megapixel CMOS sensor in the Tetracam ADC camera compared with 6 to 7 megapixel CCD sensors in the color-visible cameras. Another less obvious factor has to do with how near-infrared radiation interacts with green leaves in the canopy of emergent vegetation, as elaborated below.

Vegetation — The strong near-infrared reflectivity of active "green" leaves was discovered nearly a century ago, and is known as the Wood Effect after Prof. R.W. Wood who first photographed this phenomenon in 1910 (Finney 2007). Near-infrared radiation (~0.7 to 1.3 μm wavelength) is strongly scattered by leaf cell walls, but some near-infrared energy passes through an individual leaf and may interact with adjacent leaves or soil. Note that chlorophyll is not the source of strong near-infrared reflectivity for green leaves (Finney 2007). The result is multiple scattering of near-infrared radiation from overlapping leaves in the canopy, creating strong return signals; whereas, red and blue wavelengths are strongly absorbed and green light is only weakly reflected by the canopy (Murtha et al. 1997).

At the times of our field tests, the primary emergent marsh plants were great bulrush (*Scirpus validus*), blunt spike rush (*Eleocharis obtusa*), and small stands of cattail (*Typha* sp.), all of which grow in carpets or patches of closely spaced, upright leaves and stalks. This structure appears to enhance multiple strong scattering of the near-infrared, which infills and reduces shadows within the vegetation canopy, so that fine spatial details are obscured.

On the basis of these spatial and spectral issues, color-visible kite aerial photographs reveal different types of emergent wetland vegetation more effectively than do the color-infrared images. Nonetheless, the near-infrared-to-red ratio of color-infrared images may be utilized to determine various vegetation indices, such as the normalized difference vegetation index (NDVI), which are important for ecological studies of biomass, leaf area index, and photosynthetic activity (Tucker 1979; Murtha et al. 1997).

Water bodies — Water reflects blue light, but reflectance drops off sharply for green and red light and is essentially zero for near-infrared radiation (Wiesnet, Wagner and Philpot 1997). The result in color-infrared imagery is that water bodies appear dark blue to black, regardless of water depth or turbidity, except for sun glint noted above. At the times of our field tests, some portions of TNC marshes were filled with muddy water from recent runoff, and other portions contained water with little suspended sediment. This is clearly portrayed in color-visible photographs, but all water bodies are dark blue to nearly black in color-infrared images.

One problem for wetland image interpretation is to separate sediment-rich water bodies from bare wet soil with similar appearance. Shallow muddy pools and moist mudflats may be nearly identical in the visible portion of the spectrum. Color-infrared photographs depict a sharp contrast between water bodies, regardless of their depth or suspended sediment, and exposed soil or emergent vegetation. However, submerged aquatic vegetation is seen better in color-visible imagery (Tiner 1997).

Conclusions

• The digital Tetracam ADC camera is suitable for kite aerial photography, and its images are generally comparable to film-based color-infrared photographs.

• Tetracam ADC images from Cheyenne Bottoms are high-contrast pictures with emergent vegetation depicted in bright red, magenta, and pink colors, whereas water bodies are dark blue to black.

• Because blue light is excluded, the sky, shadows, and water bodies are relatively dark compared with color-visible photographs. However, sun glint may be quite strong in color-infrared images.

• Tetracam ADC photographs are less sharp than color-visible images, because the CMOS sensor has lower spatial resolution compared with color-visible digital cameras used by the authors. Furthermore, multiple scattering of the near-infrared tends to reduce shadows within the vegetation canopy, so that fine spatial details are blurred.

• Color-visible digital photographs are superior for identification of emergent vegetation zones, because of sharper spatial detail, and color-infrared imagery is valuable for deriving vegetation indices.

• Digital color-infrared KAP effectively separates water bodies of all types from emergent vegetation, bare soil, and other features. However, color-visible images are more effective for displaying differences in water turbidity and revealing submerged aquatic vegetation.

• For improved results overall, a combination of color-visible and color-infrared digital cameras is recommended for environmental field studies employing kite aerial photography.

Acknowledgements

Funding to purchase the Tetracam ADC camera was provided by a grant from the Emporia State University Foundation. Additional financial support came from KansasView and the Kansas Space Grant Consortium. The following ESU students assisted with kite aerial photography at Cheyenne Bottoms in June 2008: P. Johnson, J. Matthews and M. Unruh. The authors thank S. Egbert for reviewing the manuscript and suggesting several improvements. Special thanks to R. Penner of the Kansas Nature Conservancy at Cheyenne Bottoms.

Literature Cited

Aber, J.S., Aaviksoo, K., Karofeld, E. and Aber, S.W. 2002. Patterns in Estonian bogs as depicted in color kite aerial photographs. Suo 53(1):1-15.

Aber, J.S. and Aber, S.W. 2001. Potential of kite aerial photography for peatland investigations with examples from Estonia. Suo 52(2):45-56.

Aber, J.S., Aber, S.W. and Leffler, B. 2001. Challenge of infrared kite aerial photography. Kansas Academy of Science, Transactions 104:18-27.

Aber, J.S., Aber, S.W., Pavri, F., Volkova, E. and Penner, R.L. 2006. Small-format aerial photography for assessing change in wetland vegetation, Cheyenne Bottoms, Kansas. Kansas Academy of Science, Transactions 109:47-57.

Aber, J.S., Eberts, D. and Aber, S.W. 2005 Applications of kite aerial photography: Biocontrol of salt cedar (*Tamarix*) in the western United States. Kansas Academy of Science, Transactions 108:63-66.

Aber, J.S., Sobieski, R., Distler, D.A. and Nowak, M.C. 1999. Kite aerial photography for environmental site investigations in Kansas. Kansas Academy of Science, Transactions 102:57-67.

Aber, J.S., Zupancic, J. and Aber, S.W. 2003. Applications of kite aerial photography: Golf course management. Kansas Academy of Science, Transactions 106:211-214.

Bauer, M., Befort, W., Coppin, Ir. Pol R. and Huberty, B. 1997. Proceedings of the first North American symposium on small format aerial photography. American Society of Photogrammetry and Remote Sensing, 218 pp.

Finney, A. 2007. Infrared photography. pp. 556-562 in Peres, M.R. (ed.), Focal encyclopedia of photography, 4th edition, Elsevier, Amsterdam.

Jensen, J.R. 2007. Remote sensing of the environment: An Earth resource perspective. Pearson Prentice Hall, Upper Saddle River, New Jersey, 592 pp.

Leffler, B. 2008. Kite aerial photography on brooxes.com, http://www.brooxes.com/

Mace, T. H., Williams, D.R., Duggan, J.R., Norton, D.J. and Muchoney, D.M. 1997. Environmental monitoring. pp. 591-612 in Philipson, W.R. (ed.), Manual of photographic interpretation, 2nd edition, American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland.

Malin, D. 2007. False-color photography. p. 533 in Peres, M.R. (ed.), Focal encyclopedia of photography, 4th edition, Elsevier, Amsterdam.

Murtha, P.A., Deering, D.W., Olson, C.E. Jr. and Bracher, G.A. 1997. Vegetation. pp. 225-255 in Philipson, W.R. (ed.), Manual of photographic interpretation, 2nd edition, American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland.

Tetracam 2008. Tetracam ADC installation and operation (rev. 1.5). http://www.tetracam.com/DC%20User%20Manual.pdf

Tiner, R.W. 1997. Wetlands. pp. 475-494 in Philipson, W.R. (ed.), Manual of photographic interpretation, 2nd edition, American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland.

Tucker, C.J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of the Environment 8:127-150.

Warner, W.S., Graham, R.W. and Read, R.E. 1996. Small format aerial photography. American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, 348 pp.

Wiesnet, D.R., Wagner, C.R. and Philpot, W.D. 1997. Water, snow, and ice. pp. 257-267 in Philipson, W.R. (ed.), Manual of photographic interpretation, 2nd edition, American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland.