Near real-time high-resolution airborne camera, AEROCam, for precision agriculture

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Near real-time high-resolution airborne camera, AEROCam, for precision agriculture

Xiaodong Zhang\textsuperscript{a*}, Ho Jin Kim\textsuperscript{b}, Clinton Streeter\textsuperscript{b}, David A. Claypool\textsuperscript{c}, Ramesh Sivanpillai\textsuperscript{d} and Santhosh Seelan\textsuperscript{e}

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Precision agriculture often relies on high-resolution imagery to delineate the variability within a field. Airborne Environmental Research Observational Camera (AEROCam) was designed to meet the needs of agriculture producers, ranchers, and researchers, who require high-resolution imagery in a near real-time environment for rapid decision support. AEROCam was developed and operated through a unique collaboration between several departments at the University of North Dakota, including the Upper Midwest Aerospace Consortium (UMAC), the School of Engineering and Mines, and flight operations at the John D. Odegard School of Aerospace Sciences. AEROCam consists of a Redlake MS4100 area-scan multi-spectral digital camera that features a 1920 $\times$ 1080 CCD array (7.4-μm detector) with 8-bit quantization. When operated at $\sim$2 km above ground level, multispectral images with four bands in the visible and near infrared have a ground sample distance of 1 m with a horizontal extent of just over 1.6 km. Depending on the applications, flying at different altitudes can adjust the spatial resolution from 0.25 to 2 m. Rigorous spectral and radiometric calibrations allow AEROCam to be used in a variety of applications, qualitative and quantitative. Equipped with an inertial measurement unit (IMU) system, the images acquired can be geo-referenced automatically and delivered to end users near real time through our Digital Northern Great Plains system (DNGP). The images are also available to zone mapping application for precision farming (ZoneMAP), an online decision support tool for creating management zones from remote sensing imagery and data from other sources. Operational since 2004, AEROCam has flown over 250 sorties and delivered over 150,000 images to the users in the Northern Great Plains region, resulting in numerous applications in precision agriculture and resource management.

Keywords: precision agriculture; AEROCam; remote sensing; near real time; high resolution; ZoneMAP; DNGP

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Introduction

Spatial imagery has been used for crop management since 1929, when aerial photography was used to map soil resources (Seelan et al. 2003b). Compared to satellite-based sensors, images from aircraft-based sensors have a unique role for monitoring seasonally variable crop/soil conditions and for time-specific and time-critical crop management (Moran et al. 1997). For example, Lamb and Brown (2001) suggested to use airborne remote sensing for identifying and mapping weeds in crops because of its ability to generate timely and accurate weed maps. Aerial photographing and imaging techniques have been developed (e.g. Everitt and Nixon 1985, Ahern et al. 1986, Everitt et al. 1986, King 1995) for a variety of precision agriculture practices, such as monitoring crop condition, growth and yield (e.g. Yang et al. 2001, Peña-Barragán et al. 2010), delineating management zones (e.g. Fleming et al. 2000), and detecting weeds (e.g. Brown et al. 1994).

While typically offering a finer spatial resolution (1–5 m) than satellite observations (15–30 m, e.g. SPOT, Landsat, or ASTER), airborne remote sensing typically incurs higher costs due to the usage of aircrafts and crew time. Therefore, despite its potential in precision agriculture, airborne imagery is seldom used routinely by agricultural producers or ranchers. To overcome these limitations, the Upper Midwest Aerospace Consortium (UMAC) developed and has been flying the Airborne Environmental Research Observation Camera (AEROCam), providing high-resolution images for non-commercial applications in the Northern Great Plains regions of the USA (Sivanpillai et al. 2008). Images are typically acquired during the growing season of the area (May to October) and provided at no cost to the users in near real time through the Digital Northern Great Plains system (Zhang et al. 2010a). Users can also access AEROCam images through our other projects, such as zone mapping applications for precision farming (ZoneMAP) (Zhang et al. 2010b).

The capability for researchers and end users to combine and compare radiometric measurements and derived products from multiple remote sensing instruments or from one instrument at multiple times is essential. The accuracy or validity of these analyses is critically linked to the calibration of sensors. While for satellite-based instruments, the process involves the pre-launch calibration and the assessment of the post-launch calibration (Teillet et al. 2001, Thome 2001, Pagnutti et al. 2003, Thome et al. 2004), an airborne sensor, such as AEROCam, relies on carefully executed laboratory calibration, often repeated periodically, to assess its radiometric performance during the lifetime of operation. Multispectral airborne imagery has been widely used in precision agriculture and agricultural production management (e.g. Zhang et al. 2009, Huang et al. 2010); however, few studies have reported the calibration results. AEROCam project started in 2001 and became fully operational in 2004, resulting in numerous successful applications in researches, education and precision farming practices (Sivanpillai et al. 2008, 2012, Zhang et al. 2010b). To ensure the quality of data and derived products, the spectral and radiometric characteristics of AEROCam were determined through a series of calibration. Here we report the development and calibration of AEROCam and provide a few examples demonstrating the potential of AEROCam images in precision agriculture.

Methods

The development of AEROCam went through two phases: a prototype four-camera configuration and an operational single-camera configuration. Even though the
spectral band passes of the two systems are the same, the simultaneous calibration of four cameras and the co-registration of their respective images posed a significant challenge, which led to the adoption of a single camera system that has been operational since 2004 and is the focus of this study.

The current AEROCam consists of a Redlake MS4100 area-scan multi-spectral digital camera that features a 1920 × 1080 CCD array (7.4-μm detector) with 8/10-bit quantization. With four spectral bands at blue, green, red, and near-infrared, the camera can record images in either true colour or standard false colour (near-infrared, red, and green) format. The system also includes an inertial measurement unit (IMU), GPS, and specially designed software application for image acquisition planning, processing, and archiving. When operated at ~2 km above ground level, images have a ground sample distance of 1 m with a horizontal field of just over 1.6 km. Ground sample distances within the range of 0.25–2 m can be accommodated depending on user requirements and mean elevation of the site. While capable of 10-bit quantization, the camera is set at an 8-bit quantization in operation, mainly for the following two reasons. First, a 10-bit quantization results in an image four times bigger, restricting the number of images that can be acquired during one mission, which usually lasts several days over multiple locations in an ‘isolated’ manner. However, recent availability of high capacity external hard drives does make this less restrictive than it used to be. A more stringent constraint is data throughput rate from the camera to the onboard storage. To ensure the quality and continuity of the final image, sequential images are often acquired with an overlap of 30–50% to overcome occasional jittering of the aircraft during acquisition and its blurring impact on the image. At higher spatial resolution of 0.5 m or less, the sampling rate needs to be at least 1 Hz or faster to ensure the required overlap. But with a 10-bit quantization, the adequate sampling rate cannot be maintained, resulting in little overlap or even void between sequential images.

The camera system was developed and operated through collaboration between UMAC, the School of Engineering and Mines, and the John D. Odegard School of Aerospace Sciences, all at the University of North Dakota. Requests for image acquisition are announced and selected before the growing season starts. Depending on the total number of requests, flying conditions, and cloud cover, efforts have been made to fulfill as many requests as possible. Event-driven requests, such as damage assessment after a storm, are also considered. Since becoming fully operational in 2004, AEROCam has flown over 250 sorties and delivered over 150,000 high-resolution multispectral images at no costs to the users in the Northern Great Plains region, including the states of Minnesota, North Dakota, South Dakota, Montana, Wyoming, and Idaho.

Spectral and radiometric calibration

AEROCam is intended to be used for both scientific and practical applications in precision agriculture and natural resource management; therefore precise determination of its electronic, optical, spectral, and radiometric characteristics is needed. In collaboration with the Airborne Remote Sensing Laboratory at the NASA Ames Research Center (Brown et al. 2005), we fully characterized the electro-optical components of the AEROCam, producing these primary measurements sets: (1) bandpass spectral responsivity; (2) raw output in digital number throughout the dynamic range of the camera, corresponding to known radiometric input levels; and
(3) digital number output response to a Lambertian illumination at different integration times.

Spectral responses

Spectral characterization was performed using an Oriel 7345 tunable narrowband monochromator (Oriel Instruments, Stratford, CT), with associated Quartz Tungsten Halogen light source, changeable reciprocal linear dispersion gratings, off-axis parabolic mirror collimator, and turning mirror with a surface accuracy \( < \lambda/4 \), where \( \lambda \) is the wavelength. The full width at half maximum (FWHM) for the collimated light is 1.5 nm. A full spectrum scan at a wavelength interval of 20 nm was first performed to determine the approximate spectral response curve and the peak response for each band. Then for each band, the spectral response was determined at a fine wavelength interval of 5 nm. Before and after each spectral response measurement, reference scans were taken using a calibrated silicon photodiode to monitor the stability of the light source. Figure 1 shows the normalized spectral response curves determined for AEROCam. There is an overlap in the spectral response between the blue and green bands. Since there are only three CCD sensors, only three spectral images can be recorded at one time. Because of this spectral overlap, it is recommended to use images recorded in the green, red, and near-infrared bands. But when the blue band is desirable, e.g. over a water body, the camera can be configured to record images in the blue, green, and near-infrared bands.

The spectral bands for AEROCam were selected to approximately match bands 1–4 of Landsat-5 TM sensor (Figure 1), a widely used satellite sensor for precision agriculture (e.g. Seelan et al. 2003b, Thenkabail, 2003). The spectral characteristics also closely match those commercial high-resolution satellite sensors, such as IKONOS, QuickBird, and GeoEye (Table 1).

Flat field

Because no two CCD detectors are the same, it is expected that the quantum efficiency is different for different CCD detectors. Also the artifacts in the optical

![Figure 1. Normalized spectral response curves determined for AEROCam are compared with those for bands 1–4 of Landsat 5 TM sensor.](image-url)
system will alter the distribution of radiation impinging upon the CCD array. Combination of these two factors leads to differences in photo-electric responsivity by different CCD detectors. Because of this, even a uniform illumination may not appear as a flat field in the image.

Images were obtained from a flat-field uniform source, which is produced using diffuse glass emission plate with multiple reflective internal baffles between the output plate and an adjustable stable light source. The exiting light field is within 1% Lambertian for angles up to 30°. Placement of the camera within a few centimetres of the output diffuser further improved quality of the exiting light field, as near-field de-focus effects averaged any residual source variations from dust or other minor source defects. The light intensity was fixed during the experiment and the camera was set with f-stop 8, gain 12, and integration time of 4, 5, and 1.2 ms for the red, near-infrared, and green/blue bands, respectively. An example of the red band image is shown in Figure 2 and apparently the photo-electronic responsivities are not uniform across the CCD array. Contrary to the vignette effect that is typically associated with a lens system where the illumination and hence the CCD response would drop as a ray moving from centre to the edges of a CCD array (Jia and Tang 2005), the camera used in AEROCam shows an elevated response towards the edges. The similar patterns were observed for the other bands too. The AEROCam camera has a CCD array of $1920 \times 1080$ detectors, the flat field correction is determined for each CCD detector. From Figure 2, a ratio is formed for each CCD detector of its value to the mean value of the central $4 \times 4$ CCD detectors. The ratios, or flat-field correction coefficients, were then applied to a raw image to correct for non-uniform photo-electronic responsivities of the AEROCam sensor.

<table>
<thead>
<tr>
<th>Spectral and spatial resolutions of AEROCam and their comparison with high-resolution satellite sensors of IKONOS, QuickBird, and GeoEye.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Blue (nm)</strong></td>
</tr>
<tr>
<td>AEROCam</td>
</tr>
<tr>
<td>QuickBird</td>
</tr>
<tr>
<td>GeoEye</td>
</tr>
</tbody>
</table>

Figure 2. A near-infrared band AEROCam image over the flat-field uniform light source (a) and the flat-field correction coefficients (b). The image was linearly stretched to highlight the non-uniformity in photo-electronic responsivity.
Table 2. The dark current values ($O$ in Equation (1)) radiometrically determined for each band of the AEROCam.

<table>
<thead>
<tr>
<th>Band</th>
<th>NIR</th>
<th>Red</th>
<th>Green/blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark current</td>
<td>0.153</td>
<td>0.125</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Radiometric calibration

Radiometric characterization was performed using a 30 in. (76.2 cm) Archi 12-bulb integrating sphere calibrated to an FEL lamp traceable to the US National Institute of Standards and Technology (NIST) standard of spectral irradiance. The opening aperture of the integrating sphere is 25 cm in diameter and the camera was placed 9 cm from the aperture. Since the field of view angle of AEROCam is $114^{\circ}$, 9 cm is the maximum distance away from the aperture to ensure the integrating sphere covering the entire field of view of the camera. The purpose of radiometric calibration is to determine the values of gain ($G$) and offset ($O$) such that the radiance ($L$, W/m² sr µm) of the incident light can be calculated from the digital number (DN) recorded by the camera:

$$L = DN \times G + O.$$  \hspace{1cm} (1)

During the calibration, the offset ($O$), or the dark current, was determined first by taking images with the lens capped. Dark current is thermally generated electrons that build up in the CCD detectors. Dark current sometimes varies with the electronic gain settings. To simulate the ambient thermal condition as close to operational temperature as possible, the camera was powered on and ran for an hour before the images were taken with the same camera settings as its nominal operation which are f-stop 8 and gain 12. Ten images were taken and for each image DN values of 100 pixels from the image centre were extracted and averaged. The AEROCam dark current for each spectral bands was estimated as the mean of central DN values of the 10 images. The dark currents determined for all the four spectral bands, presented in Table 2, are all less than one unit digital count, suggesting that the offset $O$ in Equation (1) can be ignored in estimating radiometric calibration coefficients.

In determining the value of gain ($G$), the light levels were adjusted from three lamps up to six, nine, and 12. At each level, multiple images were taken corresponding to different combinations of f-stop, gain settings, and integration time. Ideally, the value of $G$ in Equation (1) should be estimated from a series of images acquired under different light intensity (e.g. Olsen et al. 2010). Unfortunately, at f-stop = 8 and camera gain = 12, the most commonly used setting for acquisition, the AEROCam saturates when the number of lamps was above 6. Therefore, only the images acquired under three-lamp illumination were used in determining the $G$ value in Equation (1). Table 3 lists the gain values determined for f-stop = 8 and camera gain = 12. The gain values for other settings were also determined similarly. The use of 10-bit quantization will not avoid saturation, the level of which is mainly determined by the gain setting and the integration time.
**Band alignment**

The AEROCam camera uses a beam splitter prism and three CCD sensors to acquire multispectral imagery. The three CCD sensors are aligned internally. During calibration and operation, no misalignment has been observed.

**Performance assessment**

Like any optical systems, the performance of AEROCam is expected to change or degrade over time. To ensure the quality of images acquired, AEROCam has been calibrated regularly once every 2–3 years. Since its operation in 2004, two calibrations were conducted in 2007 and 2009, respectively. Except for the noticeable degradation of the red filter, which was replaced subsequently, the radiometric and spectral characteristics of the camera remain stable between the two calibrations. As both number of end users and types of applications increase steadily, we will continue to monitor and evaluate the quality of AEROCam images.

**Results and discussions**

The calibrations allow a precise characterization of the spectral and radiometric performance of the camera. These calibrations, schematically shown in Figure 3, are applied to all the AEROCam images automatically immediately after their acquisition. An example of the flat-field correction is shown in Figure 4, displaying a standard false colour image acquired over a farm field in Lingle, Wyoming (USA). As can be seen from a profile along a CCD line, the image after the correction appear more uniform, particular towards the sides of the image. The high-resolution imagery delivered by AEROCam has resulted in numerous positive outcomes in both production agriculture and research applications.

**Deriving sunflower height from AEROCam imagery**

Validating AEROCam pixel brightness values using field measured data is an essential step prior to routine monitoring and mapping applications. To assess the utility of AEROCam images for crop growth monitoring, its pixel values were compared to sunflower (*Helianthus annuus*, cv. ‘Garst NuSun 424’) crop height in a 1.87-ha field located at the James C. Hageman Sustainable Agriculture Research and Extension Center (SAREC) in Goshen County, Wyoming. Sunflower was planted in

<table>
<thead>
<tr>
<th>Integration time (ms)</th>
<th>NIR</th>
<th>Red</th>
<th>Integration time (ms)</th>
<th>Green</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.1480</td>
<td>1.0977</td>
<td>1.1</td>
<td>0.7359</td>
<td>0.834</td>
</tr>
<tr>
<td>3</td>
<td>1.3010</td>
<td>0.6473</td>
<td>1.2</td>
<td>0.6429</td>
<td>0.6989</td>
</tr>
<tr>
<td>4</td>
<td>0.8718</td>
<td>0.4143</td>
<td>1.3</td>
<td>0.5596</td>
<td>0.6056</td>
</tr>
<tr>
<td>5</td>
<td>0.6108</td>
<td>0.2691</td>
<td>1.4</td>
<td>0.4833</td>
<td>0.5246</td>
</tr>
<tr>
<td>6</td>
<td>0.4318</td>
<td>0.1704</td>
<td>1.5</td>
<td>0.4213</td>
<td>0.4573</td>
</tr>
<tr>
<td>7</td>
<td>0.3060</td>
<td>0.0985</td>
<td>1.7</td>
<td>0.3153</td>
<td>0.3361</td>
</tr>
<tr>
<td>8</td>
<td>0.2096</td>
<td>0.0462</td>
<td>2</td>
<td>0.194</td>
<td>0.1888</td>
</tr>
</tbody>
</table>
76-cm rows at a population of 44,478 seeds ha$^{-1}$. Plant heights of 370 plants were measured on 22 August 2006 at the beginning of flowering, or growth stage R-5.1 which is when ‘ray flowers are fully extended and all disk flowers are visible’, according to the method of Schneiter and Miller (1981). For purposes of uniformity, height to the base of each head was measured and rounded to the nearest 5 cm. The location of each measurement was recorded with a Trimble Pro-XRS differential global positioning system (Trimble Navigation Ltd., Sunnyvale, CA) which had submeter accuracy after differential correction of data.

Sunflower heights were highly variable in the field. One contributing factor is water availability. Irrigation water tends to accumulate in the tracks which range from 15 to 30 cm deep. Water could flow over 100 m and accumulate in low places in the field. Accumulation of water due to microtopography has been observed in areas under the sprinkler. A pattern of greater sunflower growth near some sprinkler tracks was observed which is also visible in the AEROCam images. Since the field is located on a stream terrace, soil variability, particularly depth to sand or gravel, would affect soil water-holding capacity, which could be another factor affecting sunflower heights. Bajehbaj et al. (2009) found that when sunflower was subjected to water-deficit stress, plant height, leaf area index, and other traits were significantly decreased. In August of the study year, a mechanical breakdown resulted in no
application of water for 2 days during this critical growth period. This could have exacerbated variability due to differences in water-holding capacity across the area.

AEROCam imagery acquired on 23 August 2006, 1 day after the field data were collected, were geo-referenced using a 1 m, Digital Ortho Quad (DOQ) obtained from the Wyoming Geographic Information Science Center, University of Wyoming. The AEROCam image was referenced to UTM projection, NAD83 and GRS ellipsoid and the overall root mean square was $5^{1}$ m. Locational data were overlaid on the AEROCam image (Figure 5(a)) and brightness values in the near infrared, red, and green bands for each site were extracted using the Area of Interest (AOI) tool in ERDAS IMAGINE (ERDAS, GA, USA). The dependent variable (sunflower height) was regressed against the three independent variables derived from AEROCam spectral images using a linear stepwise regression method. This method will select a subset of independent variables that would account for most of the variability in the field measured sunflower height values.

Pena-Barragán et al. (2010) found that the yield of sunflower correlated well with values at the green, red and the NIR bands of airborne imagery during the early development stage but the correlation was poor if images were taken during flowering stage. The AEROCam images were taken during the flowering stage; but we found a linear model that incorporated red and green bands accounted for 75% (adjusted $R^2$, $n = 105$, $F$ value = 155.6 and $p < 0.0001$) of the variability in sunflower height values (Figure 5(b)). This might be due to significant correlation observed

Figure 4. A false colour AEROCam image acquired on 24 June 2009 over a farm field in Lingle, Wyoming before (a) and after (b) flat-field correction was applied. The variations of pixel values along a profile line (yellow line in (a)) before and after the flat-field correction are shown in (c).
between height and leaf area of sunflowers (Yasin and Singh 2010). Values in the green band ($t$ value $= 16.22; p < 0.0001$) were positively correlated while red values ($t$ value $= -7.8; p < 0.0001$) were negatively correlated with crop height. Despite the variability in crop growth AEROCam data were able to account for 75% of the variation in field data. Studies have shown that nutrient uptake and grain yields in winter wheat showed significant spatial variability and this was associated with differences in crop height (Freeman et al. 2007). Machado et al. (2002) showed that plant height could account for 90% variation in total plant dry matter and 61% variation in grain yield during a dry year. The sunflower height is just an intermediate product in our research. However, it does demonstrate the application potential of AEROCam imagery.

**Assessing crop damage due to the misapplication of fertilizer**

Early in the summer of 2009, a farmer in Wyoming hired a company to air-spread granulated fertilizer on his sugar beet fields. The application process was poorly done, producing uneven concentrations of fertilizer between passes across the field. Excessively low and high concentrations of fertilizer, mainly nitrogen, in the soil can greatly affect a crop in terms of decreased production. High concentrations of nitrogen tend to ‘burn’ up the plants and low concentrations would stunt growth. The farmer noticed after his beets had emerged that there were areas of stunted growth compared to the other areas of the field. It appeared that these affected areas also had straight edges, which would imply that they were not caused by something that would occur naturally. To help identify and map the areas in question, the farmer requested aerial imagery from AEROCam.

On 12 June, 7 July, and 25 July 2009, imagery was acquired of all of the affected fields to ‘see’ the crop in its various stages of growth (Figure 6(a)). The images were
used to determine the areas in the sugar beet fields where fertilizer was spread unevenly producing various gaps and overlaps in coverage. Questionable areas were identified and then ‘ground truthed’ to confirm what was causing the lower vegetative reflectance values witnessed in the images. Once all the areas were identified and measured (Figure 6(b)), a total of 5.7 ha were found to be affected. Based on the area calculations, the amount of revenue lost could also be calculated by taking past yield averages for each field and multiplying it by that year’s beet price. As a result, the company reimbursed the farmer for an amount of $24,000 due to the damage caused by the misapplication of fertilizer and the subsequent loss in production. Later the farmer commented ‘They paid the amount that I asked for without argument. I feel that it went smoothly because of the [AEROCam] photos and the ERDAS viewfinder software. Between the two I was able to calculate the damaged acreage and come up with a dollar amount. This is a valuable tool and one that I will find more uses for in the future.’

**Identifying rhizomania infection to sugar beet**

In the late 1990s, rhizomania, considered the most dangerous of diseases affecting sugar beet, made its way to the cooler climates of Red River Valley in North Dakota and Minnesota, which accounts for 40% of country’s sugar beet production, and posed a major threat to the two billion dollar beet industry. The disease is caused by *Beet necrotic yellow vein virus* (BNYVV) and the common soil borne fungus *Polymyxa betae* is the vector of BNYVV with sugar beets forming the ideal host. Besides reproducing and spreading to nearby plants during a season, the virus and the fungus have a survival phase where they are known to reside in the soil for over 15 years and infect the host when temperature and moisture conditions return to ideal. Breeding sugar beet cultivars with resistance to rhizomania is regarded as the most appropriate way to enable continued production of this crop in rhizomania-infested fields and also to slow the spread of the disease (Scholten and Lange 2000).

Nearly 48,600 ha or 25% of the sugar beet growing areas under the American Crystal Sugar Company, a farmer owned co-operative in the northern part of the
Red River valley, were affected by rhizomania in 2002 with an estimated loss of up to $710 per hectare. Because rhizomania-resistant cultivars available at that time normally produced less tonnage and sugar, it was very important to precisely identify the fields affected by rhizomania on which tolerant varieties can be planted in the next rotation.

Sugar beet affected by rhizomania exhibit typical foliar and root symptoms with the leaves typically turning yellow (Figure 7(a)) and the roots developing a beard-like appearance. However, rhizomania is difficult to diagnose based on foliar symptoms alone. Because infected roots are inefficient in nutrient and water uptake, general foliar symptoms are similar to water stress or nitrogen deficiency (Steddom et al. 2003). It is critical to obtain remotely sensed data at the appropriate time during the growing season, to successfully detect rhizomania.

During the summer of 2002, a farmer in St. Thomas Township in North Dakota (USA) noticed rhizomania infection in his fields and wanted to know the exact locations and spread to decide on crop rotation for the following growing season and if the resistant variety should be planted. The prototype AEROCam was flown over the field on 22 September 2002. The visual inspection of the 2-m resolution imagery showed that the rhizomania patches are distinctly detectable late in the growing season. Ground GPS measurements of the rhizomania patches were taken and superimposed on the AEROCam imagery (Figure 7(b)) to confirm locations and signatures on the imagery. This initial study helped in designing further ground based spectral measurements and in selection and classification of high and medium resolution satellite imagery covering large areas (Seelan et al. 2003a).

A visual comparison between Figures 6(a) and 7(b) would reveal a couple of quality issues in Figure 7(b): misalignment and colour misrepresentation. The image shown in Figure 7(b) was acquired using the prototype 4-camera AEROCam system, which was not calibrated. This also highlights the importance of calibration as reported in this study.

Figure 7. A rhizomania-infected sugarbeet field near St. Thomas, North Dakota. (a) Ground photograph taken on 22 September 2002 where the affected area is seen as a patch of yellow canopy; (b) AEROCam imagery on the same day with rhizomania patches seen as bright yellowish spots among healthy sugar beet seen as orange.
Conclusions
Radiometric and spectral calibrations are critical for scientific and practical applications of AEROCam imagery. With the f-stop number and camera gain fixed during operation (f-stop $= 8$ and camera gain $= 12$), the integration time is adjusted during imagery acquisition to avoid saturation. The calibration allows consistent interpretation of the imagers acquired with different integration time. Also, the AEROCam shows an unusual pattern of spatial variability across the CCD array, and the calibration ensures this spatial variability is characterized and corrected. Spectrally, AEROCam is similar to Landsat-5 TM sensor (bands 1–4) and commercial satellite sensors of IKONOS, QuickBird, and GeoEye. However, lower observational altitude allows it to image at higher spatial resolution (Table 1). AEROCam operates in two modes, planned and event-driven, the latter of which allows us to rapidly respond when needed. And for both, data will be free to end users in our region.

The combination of these factors offers some unique potentials of applying AEROCam in precision agriculture, which were demonstrated in this study with a few real applications. Development of AEROCam and delivery of its imagery at no cost to users is one of many projects that UMAC has been conducting in delivering societal benefit from space technology. With the help of AEROCam images, farmers and ranchers have benefited economically, students learn practical skills in remote sensing, and researchers are able to develop new applications.

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References


