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Assessing grain crop attributes using digital imagery acquired from a low-altitude remote controlled aircraft

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ABSTRACT

Considerable research has already been conducted using satellite and aerial imagery to observe cropping areas. However, these imagery platforms have limitations: repeatability, cloud cover, cost and poor spatial resolution. The aim of this study was to investigate the potential of detecting and mapping grain crop attributes using digital imagery acquired from a low-altitude remote controlled aircraft (RCA). The study utilised a digital camera (Kodak DC3200, 1 megapixel, 24-bit) mounted on a RCA of a high-wing cabin-design model of balsa wood construction with a 2m wingspan. The platform was powered by a 10 cc 4-stroke glow fuel (methanol) motor and has a payload of approximately 750g.

Preliminary images were acquired on 8 February 2003, over sorghum crop fields (151°54′, –27°40′) 15 km south of Toowoomba, Queensland. The images were captured at approximately 120 m (400 ft) above the ground.

Information contained in the images captured include:

- canopy density (high and low leaf area index)—due to differences in soil-type, moisture/nutrient status, etc.
- other land cover types (grass, soil, asphalt, etc.)
- unplanted areas—due to planting misses, germination problems and tree influences.
- micro-relief (topography)
- fence lines, posts and other infrastructure.

The information that this platform-sensor system can provide is potentially useful for many precision agriculture applications and farm planning in general. More work is being conducted that includes the use of infrared filter, geometric correction, multi-temporal acquisition, and the use of video camera.

KEYWORDS: Remotely controlled aircraft imaging; crop quality evaluation; low altitude remote sensing; low altitude crop sensing.

Introduction

The ability to measure the quantity (t/ha), and more recently the quality (% protein), of cereal crops has lead to an increased understanding of the causes of the spatial variations within a production unit (Jensen et al., 2001). The main drawback of the current technology is that the quantity and quality information can only be used retrospectively, and thus cannot be used to rectify deficiencies encountered during the growing season of the crop or plan niche harvesting strategies for consistent quality segregation.

If the ‘crop is the best indicator of its own environment’ (Stafford, 2000), then determining what the crop is saying will aid in the understanding of the variability within the cropping system. Arguably, the best method of assessing crop condition is from the analysis of vertically sensed imagery. This imagery can be sourced from either an aerial or a satellite platform.

Considerable research has been conducted using satellite imagery to observe cropping areas. A few examples include matching multi-temporal yield and image data (Layrol et al., 2000), spectral discrimination and separability analysis using ASTER imagery (Apan et al., 2002), and leaf area index estimations using Landsat TM (Price and Bausch, 1995). Despite the advantages, satellite remote sensing has well known limitations, such as timeliness, cloud cover, cost and poor spatial resolution (Zhang et al., 2002), that reduces its usefulness for evaluations of small areas and objects.

Images captured from an aerial platform (aerial imagery) have also been used to evaluate cropping systems. A three camera video imaging system has been developed (Everitt et al., 1995) and used to monitor growth and identify crop stress in kenaf (Cook et al., 1999). Other aerial imagery applications include crop stress investigations in cotton (Roth, 1993) and peanut (Wright et al., 2002), the prediction of grain yield (Staggenborg and Taylor, 2000) and to map within-field crop variability in wheat (Wood et al., 2003). Airborne sensors offer much greater flexibility than satellite platforms by being able to operate under clouds and having a much finer spatial resolution (Lamb and Brown, 2001).

However, aerial imagery is still costly when dedicated ‘mobilisation’ of the aircraft is required to acquire data for small areas. The costs have been documented for the acquisition of aerial digital photograph in the UK (Godwin et al., 2003). When the area imaged per flight is large, the cost per hectare is relatively inexpensive. Conversely, when the area imaged per flight is small, the cost increases dramatically. When converting the figures to Australian dollars, this study indicated that to image only 100 Ha per flight would cost $7500 per mission. This amount includes the cost of the plane, pilot, cameras and technicians to perform image calibration in the field. Conducting special missions is the predicament that we face to collect the images that we require.

For repeated data acquisition needs, especially at remote localities, even the operating cost of a light aircraft can be considerable. Using figures of a 2-hour flight time from the service centre to our remote location, in Cessna 172 (charged @ $350/hr), 5 times during the growing season, equates to $ 7000. There is also the additional cost of the camera system and processing and this total cost is a considerable portion of our research budget.

To be able to control image acquisition with a system that is portable and inexpensive would be the ideal scenario. This would give the operator more flexibility to allow for: unfavourable weather conditions, intensive acquisitions (weekly) should they be required, varying spatial and spectral resolutions, and the ability to perform a quick preliminary inspection to determine if there is a need to complete a thorough investigation. This paper investigates the potential of a remotely controlled aircraft image acquisition system to meet these requirements. While there is nothing particularly novel about the use of model aircraft in remote sensing, however its use for grain crop mapping at the tactical level of farm planning has rarely been explored. In addition, this study will attempt to develop an operational and low-cost system that will cater to the needs of multi-temporal data acquisition for grain protein mapping. Recent developments in low-cost digital camera and video systems as navigation tool show some promising possibilities.

The potential of remotely controlled aircraft

Remotely controlled aircraft, blimps and kites have been carrying payloads to capture traditional colour images using both photographic and video sensors (Ries 2003) for many years. The ‘Remote Sensing Research Incorporated’ web page (http://www.rst.org/) provides a ‘review of remotely piloted vehicles to address small-area remote sensing applications’. Research has been conducted in Japan on the use of blimps for agricultural and ecological applications (Inoue et al., 2000).

With the reduction in cost, miniaturisation and increase in resolution of charged couple devices, it is now possible to incorporate several of these devices into a single sensor that can be deployed on a remotely controlled aircraft. The imagery captured with this system has the potential to have greater utility than that provided by traditional imagery (particularly when the areas are small and in remote locations), providing cheaper and repetitive information, albeit in a geo-and-radiometrically uncalibrated form, for better crop management decisions.

One of the major obstacles in utilising a remotely controlled aircraft as a platform is the limitation in the payload that can be carried. The larger the aircraft, the larger the payload. Larger model aircraft have inherent obstacles including transportation (wings larger than 2.2 m are difficult to fit into a standard station wagon) and longer take-off and landing areas. However, larger aircraft, are inherently more stable and less responsive (take longer to react to flying changes) hence easier to fly and easier to locate in the sky (easier to judge direction of travel). Designing the remotely controlled aircraft platform is then a compromise to meet the specific needs of acceptable crop nutrient mapping.

Materials and methods

Description of the platform

The remotely controlled aircraft use in the preliminary testing was of a high-wing cabin-design model of balsa wood construction with a 2m wingspan (refer to figure 1). The platform was powered by a 10 cc 4-stroke glow fuel (methanol) motor and with a payload of approximately 750g. Hobbyists can purchase such an airframe, in kit form, that requires minimal assembly, for under $200. Additionally, the radio equipment (including a 4 channel transmitter and receiver, servos, batteries and charger) and the motor will cost respectively from $350 and $250 upward. So for under $800, you can be fully kitted out with a model plane ready to mount a camera or video system to capture images.

Figure 1 **The image acquisition system incorporating the digital camera sensor and the remote control aircraft platform**

Description of study area

Several study areas have been utilised. The images in Figures 1 to 3 were captured on 8 February 2003 at the Toowoomba Amateur Radio Model Aircraft Club flying area (151.90°, –27.66°), 15 km south of Toowoomba, Queensland. This area was utilised for preliminary testing due to its close proximity to Toowoomba, the availability of a member of the club to perform the flying, and no additional flying approval requirements. These test were conducted to provide 'proof-of-concept' and to initially determine the limitations of the system. The aircraft flew approximately 120 m (400 ft) above the ground.

Figure 2 **Individual rows and plants (captured <100 m above ground level), Toowoomba, 8 February 2003 (scale shown in metres)**

The second study was at a sorghum cropping trial site at the University of Queensland, Gatton (152.33°, -27.56°), 40 km east of Toowoomba (see figure 4 and 5). This trial was conducted to investigate the spectral responses of a sorghum crop, subjected to varying rates of fertiliser, and to assess how spectral data relates to crop yield and protein. The main datasets collected from the site included weekly spectroradiometer measurements, quadrant cuts, yield and protein at harvest, and soil moisture. As the sensor was still being developed, only a single-date image acquisition was attained for this trial. This occurred on the 18 March 2003, approximately 2 week after the crop had flowered. As the timing of this acquisition was getting well past the 'accepted window', no further imagery was taken. As the trial plots ran in E-W direction, the remotely controlled aircraft was flown into the easterly breeze to reduce ground speed, with photographs taken every 5 seconds. Black-and-white checkered linoleum squares were used as ground control points (GCPs) necessary for geometric rectification.

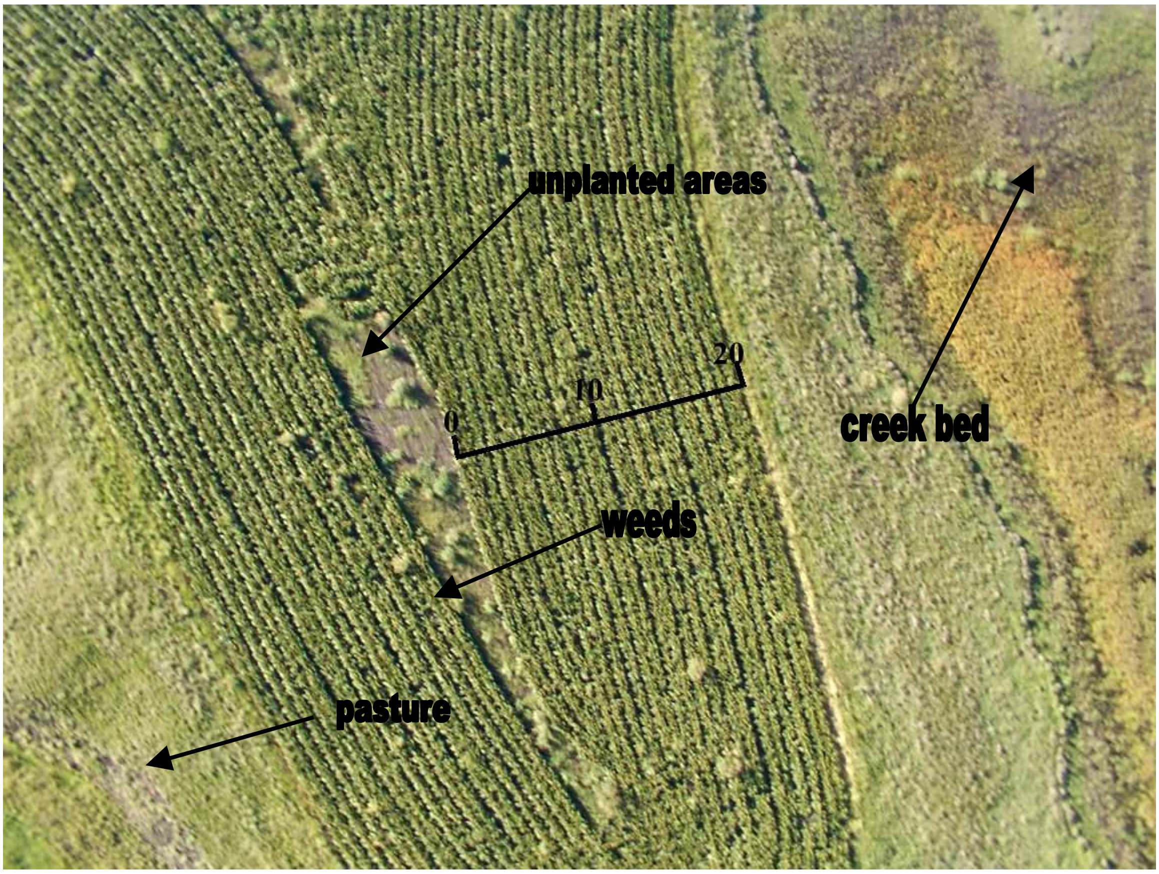

Figure 3 **Individual rows and plants (captured <100m above ground level), Toowoomba, 8 February 2003 (scale shown in metres)**

Description of sensor

The description and specifications of the Kodak DC3200 digital still camera that is being utilised as the image sensor is as follows:

- CCD resolution 1 344 x 971 = 1.31 millions of pixel
- picture resolution on best setting 1 152 x 864 = 995 328 pixels
- 24-bit, millions of colours
- JPEG file format
- glass lens with maximum aperture F/3.6
- focal length 39 mm (equivalent to 35 mm camera) 5.4 mm (actual)
- fixed focus distance of 0.6 m to infinity
- dimensions 113 mm (w) x 54 mm (d) x 81 mm (h)
- weight 215 g without batteries
- batteries 4 AA size
- picture storage 2 MB flash memory (internal) and ATA-compatible CompactFlash card (external).

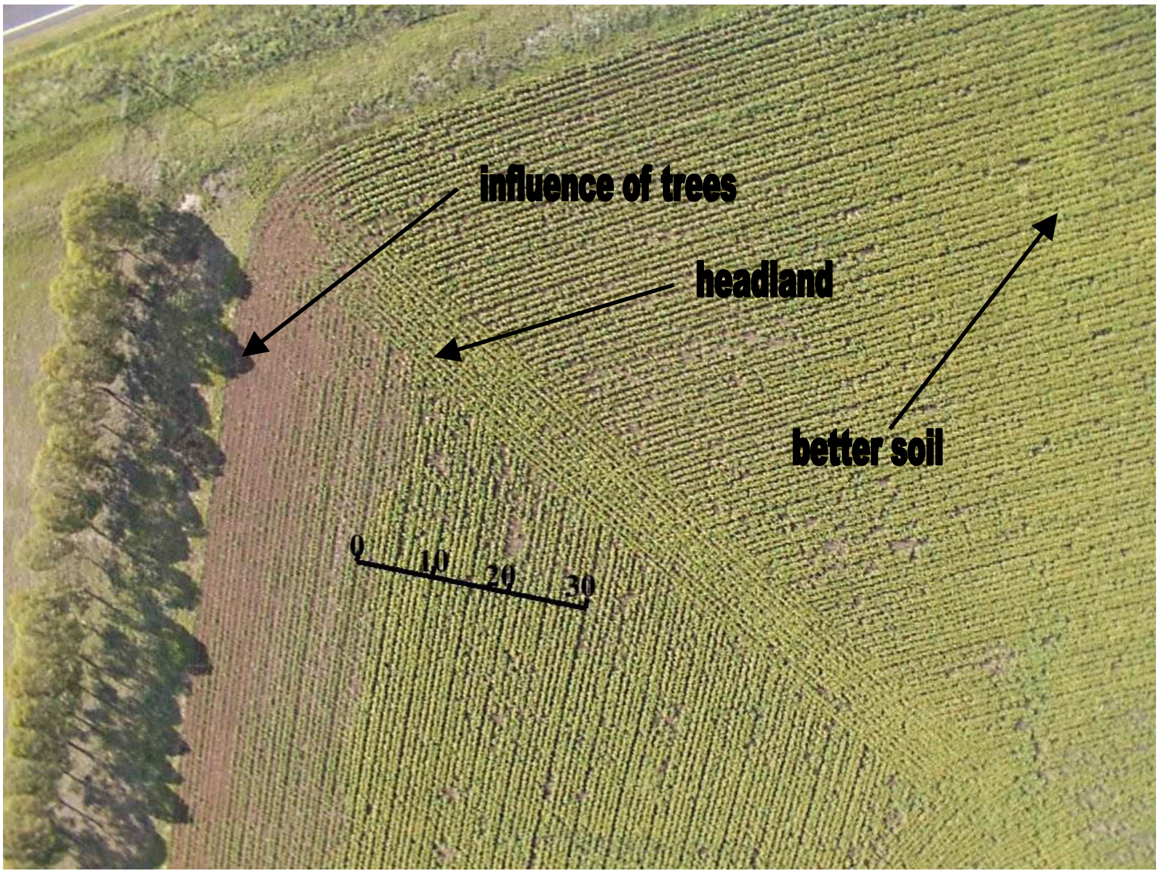

Figure 4 **The influence of trees, a soil type change and headlands (image acquired at approximately 120 m above ground level), Toowoomba, 8 February 2003 (scale shown in metres)**

The imagery shown in figures 1–5 was acquired with a single camera positioned under the fuselage of the remotely controlled aircraft. This camera, as with most charged couple devices, is sensitive in the visible and near infrared portions of the spectrum. Infrared images were obtained by placing a Hoya R72 filter in front of the lens of the camera systems. This filter is an interference filter designed to cut out all light below 720 nm. As this system utilised a single sensor, two flights were required to cover both the colour (visible) and near-infrared portion of the spectrum. A remotely activated solenoid was used to depress the shutter button when the aircraft was over the target area.

Image acquisition

The images were stored to the CompactFlash card in the camera in *'*.jpg'* format and later copied onto the hard drive of a computer using a PCMCIA adaptor for subsequent transfer into the geographic information system (GIS) package. This procedure ensures that the transfer of data is simple, easy to duplicate and requires limited computer skills to perform. At the Gatton trial site, ground control points were used to enable the correlation and analysis relationship of additional datasets (e.g. yield data) with the imagery.

Results and discussion

With the aircraft flying less than 100 m above ground level, large amounts of detail can be seen in the Toowoomba images (figures 2 to 4). Individual rows can be viewed as well as individual plants. This allows the planter misses and seeds that did not germinate to be determined. A gully can be seen clearly in figure 2, as can individual plants and rows.

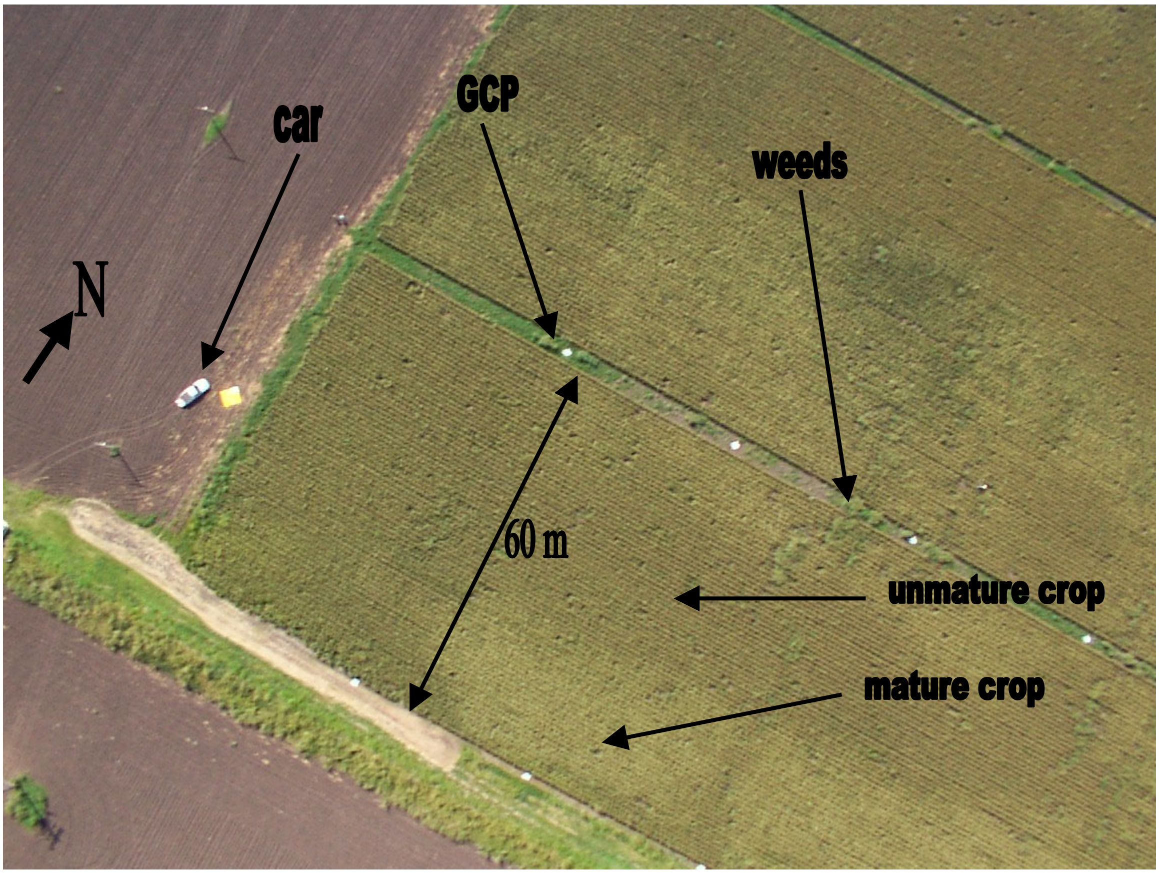

Figure 5 **Imagery of trial site showing ground control points (GCP), crop changes, weeds, ploughed field, car and power lines (acquired approximately 120 m above ground level), Gatton, 18 March 2003**

Individual plants and rows can also be seen in figure 3, as can weed species, unplanted areas, pasture areas, and a creek-bed.

At a slightly larger scale, figure 4 shows a change in soil type, the influence of trees and a headland. This image was taken at approximately 120 m above ground level.

Similar flight parameters as detailed above were used to capture images at Gatton. An example of one of the images is shown in figure 5. The individual rows can be seen as in the previous three images, but as this image was taken higher above ground level, the individual plants are not easily discernible. In the above figure, black-and-white checkered linoleum squares were used as ground control points. However, these appear as a single all white square due to the high reflectivity of the composition material. Other features viewed in this image include a white Commodore utility (centre left), power lines, cultivated ground, crop variation and weed species in the cropping area.

Immediately following the acquisition of the image in figure 5, an additional flight was flown to capture infrared imagery. The images are not shown here due to the poor quality. This poor quality was attributed to motion blur cause by the slow exposures associated with the low levels of light reaching the charged-couple-device in the camera, when used in standard consumer-packaged format. It is planned to have the camera modified to make it more sensitive in the near-infrared region. This will hopefully overcome the motion blur problems.

The images depicted in figures 2 to 5 show that this low-cost system that does not have defined photogrammetric properties exhibited a visual correspondence between image digital number and canopy density in the traditional colour bands (blue-green-red). Unplanted areas due to planting misses, germination problems and tree influences, were also captured. We can also see impressions of micro-relief, i.e. spatial variation in topography and drainage directions. Furthermore, the imagery also contains information on other land cover types (grass, soil, asphalt, etc.), as well as fence lines, posts and other infrastructure.

However, this *'off-the-shelf'* low-cost system configuration has problems capturing the near-infrared waveband. The images obtained in the near infrared were blurred and of a poor quality, due to the combination of speed of plane and the shutter speed and aperture setting of the camera. As infrared images can be successfully captured of stationery targets, insufficient light is incident on the charged couple device to make a correct exposure when the target is moving. This near-infrared information is essential to detect stressed crops and to enable the calculation of the normalised difference vegetation index (NDVI). This index and other related transformations are the basic image-related requirements for precision agricultural applications.

Future development and testing

For the current winter cropping season that commenced in June, a substantial effort is being made to collect imagery. The target is to acquire imagery, of wheat and barley paddocks, on a fortnightly basis using the model aircraft platform. The sensor now incorporates a second camera that has been specifically modified to heighten its sensitivity to the infrared range. This will enable the capture of the blue-green-red bands with one camera (as in figures 2 to 5) and the other to capture wavelengths of light above 720 nm (the near-infrared). Additionally, to aid in positioning the platform above the target areas, the sensor now incorporates a small surveillance video camera, an air to ground video transmitter and a receiver and display on the ground.

In comparison with the digital camera, the analogue video system, comprising the camera, transmitter, receiver and recorder/viewer, is more complicated. The video signal (1 volt peak to peak) from the video camera is relayed to the ground using a low power (10 mW) miniature video transmitter (2.4 GHz). A video receiver operating at the same frequency was used on the ground to receive the signal that was viewed and recorded using a digital video recorder.

The sensor (see figure 6), consisting of 2 x DC3200 digital cameras, analogue video camera and transmitter, battery packs and receiver, is a fully self-contained unit. It has a run time of 2 hours and can store 200 images per camera. With a total weight of 1.0 kg, the sensor was beyond the lift capacity of the remotely controlled aircraft that was displayed in figure 1. Currently being utilised to solve the platform problem is a 1/5-scale replica of a German post-World War 1 Eindecker fighter (see figure 7). This aircraft has a balsa construction high wing design 2200 mm wingspan and is powered by a 25 cc methanol glow motor.

Vital to this research is the assessment of geometric and radiometric qualities of the acquired imagery. This will require parallel in situ data collection at the time of image capture. We will gather time series information on crop leaf moisture content, chlorophyll status, leaf area index, and other crop related parameters. Opportunities also exist to compare RCA imagery with hand-held spectroradiometer readings, traditional airborne images (e.g. 1m ground resolution), and spaceborne data from SPOT or Landsat. Finally, the imagery from the model aircraft will be correlated to yield and protein map datasets captured at harvest.

The intensive geo-referencing and geo-rectification tasks will be carried out using ERDAS Imagine image processing software. This will allow spatio-temporal assessment, as well as the use of other map layers for statistical analyses. This package, in conjunction with ArcView, will be also used to perform image enhancements and transformations (e.g. normalised differential vegetation index, principal component analysis and/or other band ratios) and to perform image classifications. Moreover, the radiometric quality of the images will be assessed to determine their utility image for crop mapping.

The system developed will be considered useful if it enables images to be captured at suitable spatial and spectral resolutions for this level of analysis and evaluation. The possibility of high frequency acquisition of images will give the development of the image–yield/protein relationships the best chance to be found. The utility of the images will also be compared to images acquired from other commercial aerial platforms and from satellites (e.g. Landsat 7).

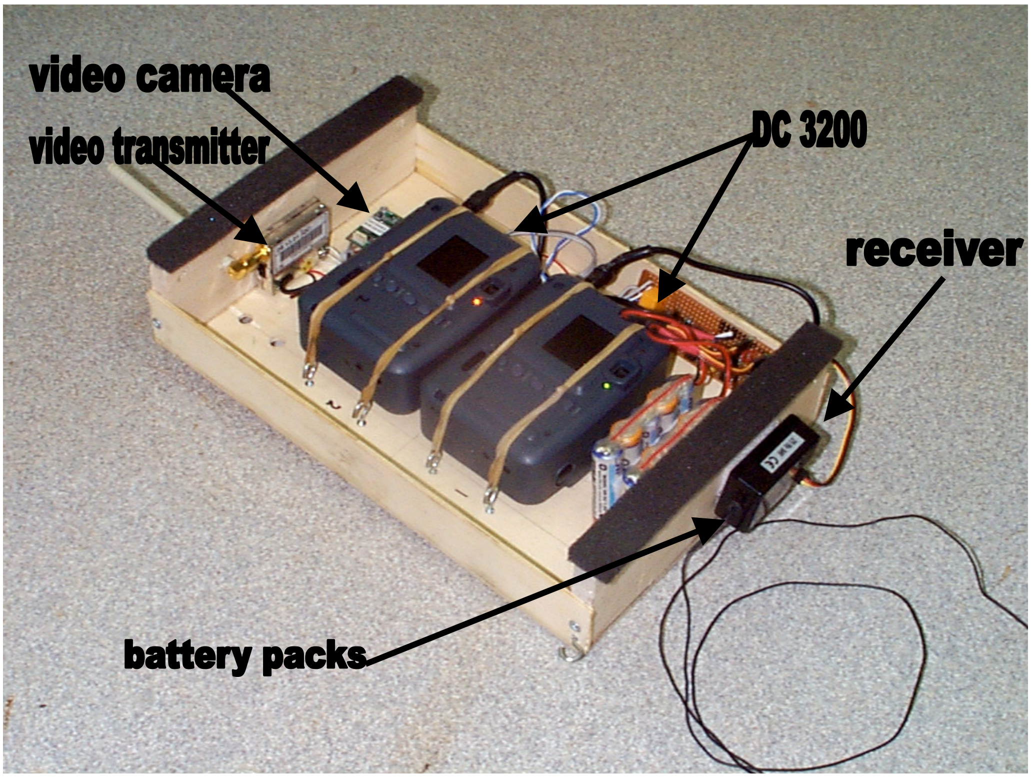

Figure 6 **The 2-camera system with video downlink currently being used**

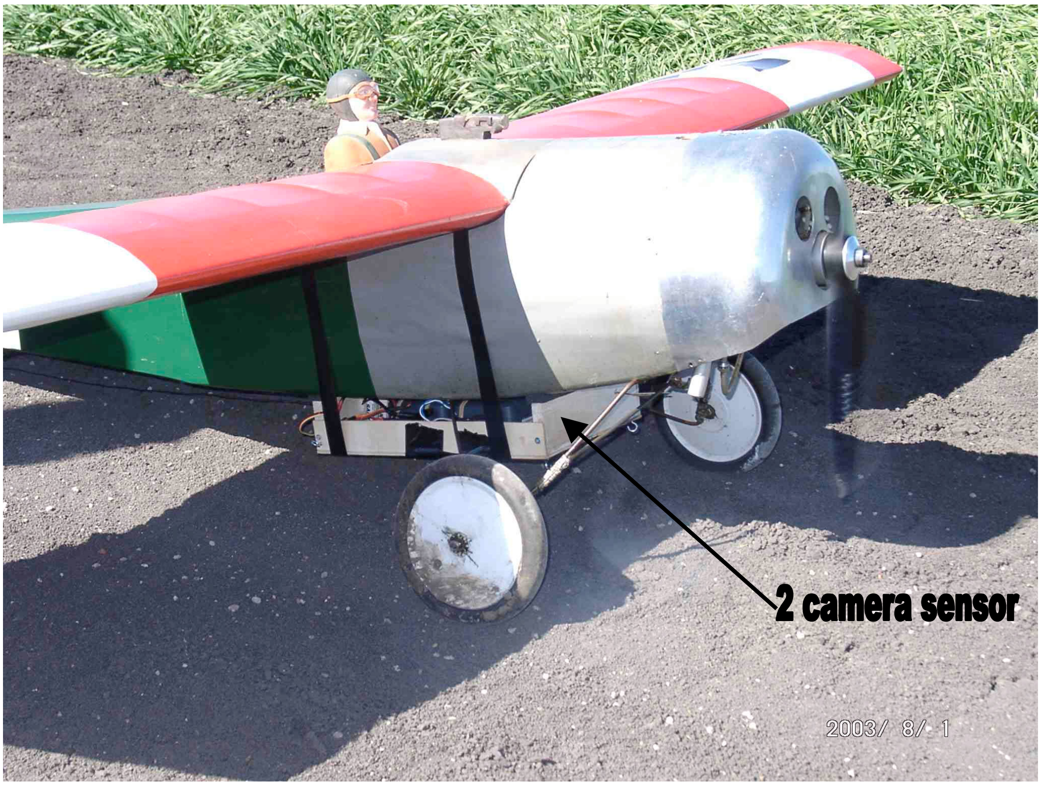

Figure 7 **The current platform with the sensor taped beneath the fuselage**

Conclusions

Although further scientific tests are needed, the initial results we achieved on the use of remotely controlled aircraft as a remote sensing platform has already shown merits for crop mapping and monitoring. The positive results have also encouraged the testing other low-altitude remote controlled platforms, such as blimps and balloons, to be explored. As the remote control and imaging technologies continue to improve, we are confident that the platform and sensor system being developing will soon offer practical solutions for precision farming and management.

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