DESIGN AND CALIBRATION OF A MULTISPECTRAL AIRBORNE DIGITAL IMAGING SYSTEM (MADIS)

G. L. McKenzie*, J. P. Louis# & D. W. Lamb#
*Spatial Analysis Unit, # Farrer Centre
Charles Sturt University
Locked Bag 588, Wagga Wagga, NSW, Australia
Phone: (02) 69 332543, Fax: (02) 69 332733 number
Email: jlouis@csu.edu.au

Abstract
The requirement for radiometrically calibrated imagery in research and consultancy activities have necessitated the design and construction of an "affordable" multispectral imaging system using off-the-shelf camera and computer-support hardware. This paper describes the design, construction and preliminary calibration of a Multispectral Digital Imaging System (MADIS) comprising four progressive-scan, 1k x 1k, digital cameras.

The cameras, with respective optical filters, are multiplexed in pairs onto two digital camera interfaces. The progressive scan architecture eliminates image shear resulting from interlaced fields produced by conventional video cameras often employed in low-cost multispectral imaging systems. The camera frame-store capability allows sequential read-off of the simultaneously triggered camera images, providing temporally registered, 4-band composite imagery. Image brightness is controlled using electronic shuttering and fixed apertures to avoid radiometric calibration errors associated with the use of continuously variable aperture controllers.

The use of 12.5 mm focal-length lenses on each camera provides 1 m resolution imagery (approximately 1 km x 1 km footprint) at an operating altitude of 1422m. The system has been designed to fit in the floor of a Cessna 310 aircraft, and only minor modifications are required for mounting it in the passenger doorway of a high-wing single-engine aircraft.

Operational, calibration and design characteristics of this new system are compared with those of an older-generation analogue multi-camera video array.

Introduction
Multispectral Air video systems are increasingly being used as a routine agricultural crop management tool, (Louis et al. 1995, Lamb 2000). The main operational advantages of these systems for agricultural applications are; their low capital and aircraft operational costs; relatively high spatial resolution and temporal flexibility for image acquisition. In the past two decades there has been a steady evolution of these systems from tape based analogue camera systems through to the current generation of digital frame camera based systems. (King 1995) gives a comprehensive review of some of the earlier systems and their design characteristics. The main factor driving the development of multispectral video systems has been the increasing availability of low-cost off-the-shelf video, computer hardware and GPS navigation components.
In addition to the continued development multispectral camera arrays, using higher resolution digital camera technology, there has also been significant progress made towards radiometrically calibrating airborne video systems to provide corrected ground radiance & reflectance data that can be calibrated to agronomic crop characteristics of interest, eg (Edirisinghe et al. 1999 and Pellikka 1998).

Over the past 5 years the Farrer Centre at CSU has gained considerable operational experience with a 4 camera analogue system based on a SpecTerra Camera array and acquisition software developed in the Spatial Analysis Unit at CSU. During the period 16/6/95 - 26/3/99 approximately 5,707 agricultural crop images have been acquired and processed. As a result of this operational experience a number of hardware and software limitations have been identified within the existing analogue system. During the development of our second-generation digital system we have attempted to identify and eliminate as many of these operational problems as possible.

**Analogue System - Operational Characteristics**

While the current analogue system has proved a reliable and valuable agronomic monitoring tool, the following operational limitations have been identified.

Interlace effects between the two frames of the analogue camera system leads to significant data loss and difficulties in subsequent image processing procedures, particularly when there was significant aircraft roll during image acquisition.

At the maximum operational altitude of an un-pressurised light aircraft, approximately 10,000 ft (AGL), the combination of 12 mm c-mount lenses and 740 x 576 pixel CCD array leads to approximately 2 m ground resolution and a maximum coverage of 170 Ha. While this is sufficient for most precision agriculture (within paddock) applications, it is limiting for a range of environmental monitoring applications.

The current analogue system is based on a standard desktop PC powered by gel cell batteries and has a standard keyboard and CRT monitor. Together with the camera array and instrument rack, this results in a heavy and cumbersome data acquisition system. While this system is within the weight capacity of a Cessna 210 aircraft, transport and installation for operational flights is difficult.

Capture and digitisation of the analogue video signal is achieved using an AT Visa board. While the AT Vista board provides some convenient on-board image processing features and the ability to simultaneously capture 4 analogue video signals, a timing mismatch between the AT Vista frame grabber and the PC bus leads to final radiometric resolution of only 7 1/2 bits.

Command input for the current data acquisition system is controlled by a conventional miniature keyboard and is not well suited for an operational aircraft environment. Furthermore the current hardware and software data acquisition configuration has not been designed to easily accept ancillary GPS spatial location and aircraft attitude information.

Operational control over the captured scene brightness is by electro-mechanical adjustment of the four camera apertures. Significant operational changes in aperture are
difficult to track accurately and can complicate image calibration procedures, particularly vignetting corrections.

Digital System - Operational Design Parameters

In designing a new replacement digital system, the aim was to take advantage of the decreasing cost of digital camera technology and to improve as many of the operational system characteristics as possible, while still maintaining the low cost status of the system with component cost under AU$100,000. In building the new digital system the principal design issues were:

1. Use of a compact & robust industrial PC for data acquisition.

2. Use of aircraft power instead of gel-cel batteries. This has been achieved by the use of Vicor DC-DC converters in the power system design. The lightweight power supply sub-system is located above the motherboard in an extension to the PC chassis.

3. The use of four 1 k x 1 k digital progressive scan cameras to:
   • Eliminate geometric interlace distortion
   • Increase the operational footprint of the imagery
   • Eliminate the need for a frame-grabber board and provide for future spectral expansion beyond the four cameras supported by a single AT-Vista board.
   • Allow software control of integration time (shutter speed) as an alternative to electro-mechanical control of aperture
   • Increase the radiometric resolution to 10 bits/pixel

4. Use of a single touch-sensitive LCD display to replace both the heavy CRT monitor and the keyboard for in-flight image monitoring and control of the data acquisition software.

5. Use of an eight port serial interface card for software control of the digital camera array. One serial port is allocated to each digital camera allowing software control over image capture as well as the black level, white level & gain settings of the internal camera analogue to digital converter (ADC). Three of the remaining ports are allocated for future data expansion for GPS navigation, in-flight radiometer and aircraft attitude monitoring.

6. Use of timing pulse control, through the digital camera interface, to allow software adjustment of individual camera integration times. While coarse software adjustments to integration time can be implemented through the serial camera interface, the much finer control (in steps of 1/16,000 sec) is available using the digital camera interface. This fine control over integration time is necessary given the practical restriction of integration times (< 3 ms) for airborne imaging applications. Integration times in excess of 3 ms are not desirable as they result in significant aircraft motion blur and require additional image post-processing.

7. Open design for camera array to allow for easy access for alignment adjustment.
Current System Status & Evaluation

Construction of the MADIS system was completed in March 2000. A view of the completed camera array, the LCD touch display & control and the data acquisition hardware is shown in Figure 1. Experimentation with camera alignment using a laboratory based target has confirmed that, as with the previous analogue system, it is not easy to align an adjustable four camera array such that the cameras are parallel and focused at infinity. In fact the alignment process has been made somewhat more difficult due to the elimination of the AT Vista board that supported simple on-board image processing features such as hardware zoom. Notwithstanding this, the system can be hardware aligned to within 2 pixels. This hardware alignment tolerance is comparable with that of the older analogue system. In both cases a final software alignment of the four-band image is required.

Figure 1 MADIS Camera Array and Data Acquisition System

Significant advances have been made in the in-flight operational characteristics of the system, with image display, system management and image capture all being incorporated within a single LCD touch screen. The data acquisition software has been written to run under the Windows NT4 operating system and is organised into five operational screens each of which can be accessed by a series of always-on-top tabs. The five operational screens are:

1. Display - Showing the output from each camera with the option of false colour image.
2. Control - Showing camera settings such as pulse width (aperture proxy), f-stop and home directory
3. Capture - Allowing for the creation of a directory for a run of images as well as the selection of primary and secondary cameras, zoom factor and the display of other relevant capture information.
4. Log - Showing a log of image acquisition events.

5. Stats - Showing image statistics from the primary camera, including an image histogram from the primary camera.

Primary camera selection buttons, primary camera image, capture and save buttons are available on every screen. As an example the statistics control screen is illustrated in Figure 2.

In addition to the improved software acquisition functionally, Table 1 gives a comparison of the hardware differences between the analogue and digital imaging systems.

<table>
<thead>
<tr>
<th>Feature</th>
<th>MAVS Analogue</th>
<th>MADIS Digital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picture Elements</td>
<td>740 h x 576 v</td>
<td>1008 h x 1008 v</td>
</tr>
<tr>
<td>Radiometric Resolution</td>
<td>8 bits (7.5 bits effective)</td>
<td>10 bits</td>
</tr>
<tr>
<td>Radiometric Range</td>
<td>4 band (400 nm – 900 nm)</td>
<td>4 band (400 nm – 900 nm)</td>
</tr>
<tr>
<td>Frame Acquisition Time</td>
<td>7.5 sec</td>
<td>7.0 sec</td>
</tr>
<tr>
<td>Frame Storage Capacity</td>
<td>100 frames</td>
<td>175 frames</td>
</tr>
<tr>
<td>Footprint at 10,000 ft AGL</td>
<td>170 ha</td>
<td>420 ha</td>
</tr>
<tr>
<td>Focal Length</td>
<td>12.0 mm</td>
<td>12.5 mm</td>
</tr>
<tr>
<td>Aperture Range</td>
<td>f1.4 – f22</td>
<td>f1.4 – f22</td>
</tr>
<tr>
<td>Integration Time</td>
<td>1 ms (fixed in-flight)</td>
<td>0.0625 ms – 3 ms (variable)</td>
</tr>
</tbody>
</table>

Table 1 Comparison of System Specifications
The principal improvements in system performance are the increased spatial footprint and radiometric fidelity. Elimination of the inter-frame interlace, and associated 1/50 sec inter-frame time delay, also improves image fidelity as well as allowing for more flexibility in aircraft speed and altitude for operational missions. The system has only flown one test mission to date and specimen imagery from that flight is illustrated in Figure 3.

Figure 3 MADIS False Colour Image

The pixel size in the trial MADIS urban-rural scene is approximately 1 m and the imagery is radiometrically uncorrected

**Conclusion and Future System Developments**

Following further test flights and system calibration work it is anticipated that the new digital system will replace the current ageing analogue system for routine agricultural and environmental monitoring work at CSU. The present analogue system currently collects 1,000 ha of agro-environmental imagery monthly.
There is a growing demand for radiometrically calibrated and large area mosaiced imagery. One of the guiding principals in designing the new digital system has been to provide scope for future ancillary data collection. While GPS data and moving map software are used during operational flights, the GPS / navigation / geo-location functionality is not well integrated into the current analogue imaging system. Future development of the new digital system includes the addition of GPS and aircraft attitude data to aid in flying large area mosaic applications and the addition of an on-board radiometer to assist in radiometric calibration of the video imagery.

References


