DEVELOPMENT AND APPLICATION OF AN AIRBORNE MULTISPECTRAL DIGITAL FRAME CAMERA SENSOR

Dr. Douglas J. King

Assistant Professor
Department of Geography
Carleton University
Ottawa, Ontario
Canada
K1S 5B6

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ABSTRACT

A low cost multispectral digital frame camera sensor is being developed for airborne remote sensing, photogrammetry and close-range applications. It consists of a 1320 x 1035 pixel black and white digital frame camera, a 15mm focal length lens (view angle ±16.7° x ±13.2°), a rotating filter wheel which houses user selectable narrowband interference filters, a high speed shutter, and a reinforced PC computer with a 1280 x 1024 frame grabber, a high capacity buffer and a large hard drive. With this configuration, the ground pixel size is between 14cm and 5m for a range of altitudes of 300m to 11,000m. Image acquisition is controlled in-flight using customized software. Several sets of multispectral imagery can be acquired quickly and held in the buffer before reading them to the hard drive or to low cost tape media. Digital frame camera technology has the potential to replace photography, line scanners and videography in many applications either because of its low cost or its superior imaging capabilities. This sensor has thus far been applied in monochrome mode for determination of x,y,z positional accuracy using analytical photogrammetric techniques. Results have shown that coordinates within an urban scene can be determined to accuracies approximately equal to the ground pixel size. Further study is under way to develop large scale digital elevation models using these methods. Multispectral imaging will commence in the summer of 1992 for assessment of vegetation damage associated with acid-mine leachate as well as other natural resources applications.

Key Words: digital frame camera sensor, multispectral, airborne.

INTRODUCTION

Digital frame cameras (DFCs) are two-dimensional solid-state imaging devices which produce a digital output signal in standard raster format. Various types of DFCs are currently available, the most common being silicon-based charge coupled devices (CCDs) incorporating imaging chips of approximately 1024 x 1024 photosites which produce an 8-bit signal. This technology has recently become much lower in cost (now < $10,000 US for some cameras) due to improved chip manufacturing and to the push for compatibility with emerging high definition television technology. Imaging chips are also available in 2000 x 2000 and 4000 x 4000 formats and/or 12-16 bit quantization but the cost of the sensor and of the associated data transfer/storage are still prohibitively high for operational remote sensing.

Several aspects of DFC technology compare favourably to other remote sensing technologies such as photography, videography and line scanning. Its advantages over standard photography include: linear response, greater radiometric sensitivity producing images of greater contrast, and wider spectral response. CCDs are sensitive from 400nm to 1100nm while others such as PtSi sensors are sensitive in the 1-5 micron range. DFCs also provide greater geometric stability (no film warping) and a digital image format which is more suited to computer image processing for radiometric enhancement and quantitative data analysis. In relation to standard solid state videography*, DFC technology provides much improved resolution. In North America, video images are typically digitized at 512 x 480 pixel density to match the National Television Standards Committee (NTSC) scanning format, therefore limiting potential resolution. The image readout rates of DFCs are also often flexible and can be tailored to specific applications. To visually compare the quality of DFC imagery, photography, and videography under equal and operational conditions, the author (in association with the Ontario Centre for Remote Sensing) simultaneously acquired data of the Toronto shoreline using 70mm colour photography, standard CCD colour video, and the Kodak DCS 1280 x 1024 colour digital frame camera (Mausel et al., 1992). The images were acquired from an altitude of 2800m at the same scale by appropriate selection of lens focal lengths. The results showed that the DFC imagery approached the 70mm photography in visual resolution and surpassed it significantly in image contrast rendition. The resolution and contrast of the colour video images were much lower, providing very little interpretable information. Finally, in relation to line scanning, the principal advantages of DFCs are: stable two dimensional frame exposure resulting in simpler geometric correction and analysis using techniques readily available for photography, near real-time availability of imagery for visual assessment or computer analysis, and capability of multiple view angles through overlapping stereo imaging.

These benefits and the continued decrease in costs provide potential for DFC technology to replace the above sensors in many applications within the next decade. The airborne multispectral digital frame camera sensor (AMDFCS) currently under development at Carleton University represents an extension of the research conducted by the author during the past nine years in airborne videography (eg. King, 1992; King and Vlcek, 1990; King, 1988). The primary objective of videography researchers has been to develop cost-effective and versatile means for remote sensing. DFC technology is an advancement over NTSC video that, although more costly at present, will replace it as a higher quality standard for low cost digital imaging device in the near future. This paper discusses preliminary specifications of the AMDFCS and potential applications of DFC technology with reference to three specific research projects which are under way.

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The AMDFCS under development includes the following components.

1. One black and white KODAK MEGAPLUS Model 1.4 DFC incorporating an 8.98mm x 7.04mm CCD sensor chip with 1320 horizontal (H) x 1035 vertical (V)

* See Mausel et al. (1992) for a review of this technology.

active photosites, each being 6.8μm square. This CCD has the smallest photosites of any commercially available camera and they are positioned with a fill ratio of 1.0. The signal is not transferred by means of shift registers between columns of photosites as is commonly done in CCDs but is transferred through the sensor during a non-exposure period. The principal advantages of such a small, densely packed sensor chip are increased resolution for a given aircraft altitude in comparison to that for a larger chip, and reduced or negligible aliasing in comparison to a sensor with shift registers between the photosites. The main disadvantages are reduced angle of view (limiting large area mapping capabilities), reduced radiometric sensitivity (requiring gains of greater than 1.0 for narrowband imaging), and greater reduction of resolution in the near IR due to crosstalk between the photosites.

2. A 15mm focal length lens provides a view angle of ±16.7° (H) x ±13.2° (V).

3. A high speed camera shutter has been added to the sensor to reduce aircraft image motion effects because the shutter supplied with the camera has a minimum exposure time of 1/100s.

4. A rotating filter wheel which can house up to six interference filters is mounted behind the lens. The rotation is synchronized with the image capture and read-out rate so that each frame of imagery is a separate spectral band. Spectral filters are user selectable within the sensitivity range of the camera (400nm - 1000nm). Currently, a set of 40nm and 10nm bandwidth filters are used.

5. Images acquired by the sensor in analog form are digitized by an 8-bit (256 grey level) A/D converter within the camera (the camera S/N is 55 db). Image read-out is routed through a 1280 x 1024 frame grabber to a large buffer capable of holding several images at once and then to a large storage micro-computer hard drive or to an Exabyte tape drive. The micro-computer is reinforced to withstand acceleration and vibration forces in the aircraft.

6. Customized software is used to capture and store images at user specified time intervals (generally for 60% overlap stereo imaging). All commands for image capture are entered in-flight and the user can view the scenes being acquired to ensure suitable target coverage. Image acquisition is a simple procedure which requires minimal user training and in-flight activity.

For an operational range of aircraft altitudes of 300m to 11,000m, using the configuration described above, the area of coverage of each scene can range from approximately 180m (H) x 150m (V) to 6600m (H) x 5175m (V), respectively. The range of the corresponding ground pixel sizes can be from 14cm to 5m, respectively. The cost of the entire AMDFCS will be less than $40,000 US.

<u>Ancillary Instrumentation</u>
The AMDFCS is mounted in a standard aerial photographic mount which provides vibration absorption. It will be combined with a spectral radiometer aligned with the centre of the field of view for calibration (following methods described in Neale, 1992). In addition, GPS will be used to record the aircraft position for simplification of image-to-map registration and to aid in initial perspective centre specification for photogrammetric applications.

<u>Calibration</u>
Radiometric calibration will be conducted using standard laboratory techniques to determine radiometric response, image brightness variations with view angle, and noise characteristics (King, 1992; Crowther and Neale, 1991) for each spectral band-aperture combination used in-flight. Field targets will also be used for calibration where possible. Geometric calibration for focal length, principal point position, and radial/tangential distortions will be carried out to improve photogrammetric analysis capabilities. The stability of the calibration will also be studied because the electro-mechanical filter wheel may introduce some variation. Finally, resolution and MTF studies will be conducted to aid in flight mission design for minimum resolvable target size.

APPLICATIONS

The AMDFCS has potential to be applied in both multispectral remote sensing and photogrammetry applications. Most airborne remote sensing applications which are currently conducted using line scanners such as MEIS II or videography sensors can be cost-effectively conducted using an AMDFCS. Example applications for natural resources include: resource inventory (at scales somewhat larger than 1:10,000 aerial photography), forest/agricultural/rangeland damage assessment, agricultural and rangeland weed infestation mapping, soil mapping (eg. type, moisture, salinity), and water pollution studies. Urban mapping applications with immediate potential include inventory of development changes (rural-urban fringe studies) and land use planning. The principal photogrammetric application is most likely large scale base mapping and elevation modelling, although many others also have potential.

The Carleton AMDFCS has thus far been applied in monochrome mode for the purpose of operational digital elevation modelling at large scales such as those suitable for urban, rural watershed or forest management. Initial results from analysis of a 2km x 1km urban scene consisting of two overlapping images with pixel size 0.7m showed positional accuracies of 24 surveyed points to be approximately 1m on average (King et al., 1991). These results were obtained using only three control points to simulate operational conditions where good control would not be available. In addition, there were no camera calibration data and the data were acquired under less than optimum imaging conditions. With improvements in these limitations, there is potential for accuracies equal to or less than the image pixel size. This research is continuing for areas of natural cover types where smaller scale imagery is being used to develop and evaluate DEM accuracy.

Multispectral remote sensing research in progress includes evaluation of forest damage associated with acid leachate generated in tailings ponds of abandoned mine sites. This is a critical problem across Canada which has not been adequately addressed from an environmental mapping perspective. The approach being taken is similar to that developed by Yuan et al. (1991) for sugar maple decline assessment using the videography system developed by King and Vlcek (1990). It involves imaging selected forest plots with pixel sizes of 0.3-0.5m and statistical evaluation of individual tree crowns for both image spectral and textural variations related to damage. The spectral bands utilized are 10nm in bandwidth centred in each of the major regions of the visible and near IR (blue (450nm), green (550nm), red (670nm) and near IR (800nm)). In addition, a flight will be conducted using several filters with central wavelength of transmission in the red edge region between 670nm and 790nm to model changes in its shape or position with variations in vegetation damage.

Another application which is currently being initiated is the determination of leaf area index and absorbed photosynthetically active radiation (APAR) using the normalized difference vegetation index (NDVI = (near IR - red)/(near IR + red)). The purpose of this study is to develop algorithms for determination of the variability and scaling up of these parameters from ground level measurements through aircraft imaging scales (30cm to 5m pixel sizes) to satellite imaging scales (30m to 1km pixel sizes) for use in large area global circulation models.

In both the above multispectral studies, experiments will be conducted using ultralight aircraft for low level (25m - 200m altitude) imaging in combination with radiometric measurement. Future use of the sensor is also planned for close-range imaging such as scanning of aerial photographs and maps for input to a GIS, microscopic image analysis of soil structure, and road deterioration monitoring.

SUMMARY

An airborne multispectral digital frame camera sensor is currently under development at Carleton University, Ottawa, Canada for low cost versatile remote sensing, photogrammetric, and close-range imaging applications. Its capabilities represent significant advances over videography and photography as well as some advantages over current line scanning techniques. Through further research, the potential of digital frame camera technology to cost-effectively replace these sensors in many applications of airborne remote sensing for natural resources and urban mapping will become apparent.

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