LOW COST INTEGRATED AIRBORNE MULTISPECTRAL REMOTE SENSING

A. ROBERTS, R.L. SHERWOOD and C. COBURN
Department of Geography
Simon Fraser University
Burnaby, BC, Canada, V5A 1S6
aroberts@sfu.ca

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ABSTRACT

For most resource management remote sensing applications, overall project costs are of critical importance. Budgets made available to individual researchers seldom permit experiments using an airborne multispectral remote sensing system. The integrated multispectral system described in this paper has a capital cost of approximately $50,000 and can be operated in most light aircraft that have a standard (40cm) camera port. This provides the potential for a low cost airborne RS system that can be made project dedicated.

The integrated airborne multispectral remote sensing systems evaluated in this study consisted of: 1. Two motor driven 35mm or 70mm reconnaissance cameras using colour and colour infrared film or one multispectral four band 24cm camera with IR Aerographic film and suitable optical filters. 2. Three optically filtered (including removable internal IR cut off filters), electronically shuttered CCD digital frame cameras integrated into an airborne direct digital recording system using an PC processor with extended RAM (256+mb), a 32bit four channel digitizing card and large capacity portable disk data storage. 3. Two CCD based VIFIS imaging spectrometers providing approximately 10nm bandwidth spectral data across the CCD spectrum (400nm to 1000nm).

Several configurations of such a multispectral integrated system was installed in the SFU remote sensing aircraft and is described and evaluated for airborne remote sensing in resource management. The imagery was evaluated for image quality, spatial and spectral feature identification and cost.

In general, the system performed well. All targets could be reliably discriminated and quantitative and/or qualitative evaluations were possible for SSC, petroleum slicks, sewage plumes, bottom reflectance and marine vegetation.

1. INTRODUCTION

Remote Sensing has been widely identified as being of considerable importance to most areas of environmental analysis and resource management. Unfortunately problems of cost and complexity have kept it as a relatively esoteric technology with limited use by most resource managers. Airborne multispectral remote sensing systems can often cost in excess of $1M and usually require relatively large aircraft due to power and space requirements. These systems are usually data collection systems and seldom have on board analytical capability. Many presently available analytical systems, for image analysis with such data, are relatively inexpensive ($5 - $20K) and have reasonably full functioned image analysis.

The system proposed here is an inexpensive ($50K) multispectral image acquisition and analysis system for use in most light general aviation aircraft. It also has full analytical capability for laboratory based remote sensing research. This system incorporates the performance capabilities of a microcomputer based image processing system with an inexpensive multispectral electro-optical and photographic imaging system. Most of the hardware and software that is necessary to achieve this goal is presently available through commercial sources. This system has been tested in a variety of research context involving aquatic environments and pollution detection in B.C. coastal waters.

2. SYSTEM DEVELOPMENT

2.1 Technical Objectives

To integrate a low cost multispectral supplementary reconnaissance photographic (SRP) and CCD based digital multispectral (DMS) airborne remote sensing system including a microcomputer based image processing systems into an intelligent multispectral airborne system for resource management applications in aquatic environments.

To refine the system for near real-time detection of critical pollution targets in water using the integrated intelligent multispectral system.

2.2 Pollution Problems

Worldwide, a small proportion of hydrocarbon pollution originates from natural sources. The large majority results from man made pollution, which can be divided into two classes (accidental and chronic). Accidental spills usually result from large volumes of oil escaping from damaged ships or offshore drilling operations. Chronic pollution comes from industrial sources and/or intentional dumping (e.g.. bilge waste from ships). Refineries, dock areas and coastal industrial regions with high industrial activity all produce waste oils and some of these will eventually get into the water system. The Vancouver, Canada, harbor region appears to suffer from chronic hydrocarbon pollution, presumably as a result of industrial activities. Intentional dumping (from waste oils dumped into municipal drains and/or ships discharging bilge water) may be the greatest contributor to this chronic hydrocarbon pollution problem. The Canadian Coast Guard and Transport Canada have also under taken regular off shore airborne patrols to detect ships dumping oil polluted wastes. Unfortunately, although these problems are generally acknowledged there has been no development of a suitable low cost dedicated remote sensing system to assist on these patrol flights and in monitoring near shore pollution in built up areas.

In a practical Canadian situation (an oil spill along the west coast of Vancouver Island, Dec. 88/Jan. 89), the only attempts to track the spill involved two Canadian thermal infrared sensors and an American microwave (radar) sensor. Due to weathering of the spill and sea state conditions, one thermal sensor was able to detect some surface components from the spill but these data were not sufficiently reliable to permit monitoring or tracking of the spill. The other thermal sensor failed and could not be used. The microwave sensor was not able to detect any traces of the spill and was of no practical use (Roberts, 1992).

2.3 Weathering Problems

Currently the gathering of real time information relating to environmental disasters, such as oil spills, is limited by scarce and costly equipment and a lack of applied research and development in actual situations. The limited utility of the thermal infrared and microwave systems on the westcoast spill example could have been predicted, due to the weathering of the oil slick for several weeks prior to the detection attempts. Two principal aspects of the weathering process, sinking and emulsification, made it practically impossible to reliably detect any more than the remaining emulsified surface components of the spill. Neither radar nor emitted infrared (thermal) energy will provide any imaging of subsurface data. Since most of the slick had probably submerged to some extent the main slick could not have been detected.

Emulsification incorporates water into the body of the slick and alters the black body (emissivity) characteristics of the oil. This changes the spectral "signature" of the oil for a thermal sensor and can cause significant confusion. Sinking is a function of changes in the specific gravity of the hydrocarbons as a result of evaporation of volatile fractions and other weathering processes.

As indicated by news media reports, the scope of disaster situations can change "by the minute" with changes in winds, tides and other natural or man-made factors. The ability to economically monitor a specific environmental situation and directly address the situation with a relevant strategy could, where implemented, reduce disaster impact significantly. The timely detection of an oil slick drifting towards a specified coastal location could provide prior warning for locating suitable booming and clean-up equipment. Although microwave and thermal systems have a proven capability with fresh spills in relatively calm seas, their high costs and limited availability makes it unlikely that they will be available upon short notice or for relatively small spills. With large spills that have weathered in rough seas these systems may be totally inadequate.

For legal purposes the offshore patrols involve low flying aircraft and the visual identification of the oil pollution and the ship. Photographic and regular colour video images are often taken through the aircraft windows. There has been no analytical attempts to identify if they are petroleum hydrocarbons and quantify the pollution. Visual identifications at low altitude can be unreliable and inconsistent.

3. INTEGRATED SYSTEM

Oil-water discrimination can be reliably achieved under a wide range of surface sea state conditions and for a variety of oil types through the use of a single camera with an ultraviolet (200-300nm) filter (Vizy, 1974). Because other non-water targets (suspended sediment and algae) could be confused with oil, a green (525-575nm) filtered camera should be used to identify bottom reflectance and turbidity and a near-infrared (700-1100nm) filtered camera to identify algae and surface vegetation. Preliminary research to identify such targets using a multispectral CCD camera package has been undertaken by Roberts (Roberts et. al., 1995; 1996; 1998; Liedtke and Roberts, 1995) and Sherwood (1987) and digitally multispectral camera package (Roberts, 1995). The camera system performed reliably: suspended sediment could be identified in quantities as small as 5 mg/l and a variety of oil types could be identified and quantified in a controlled field condition. In addition, a number of "spills of opportunity" were located and successfully imaged near Vancouver between 1987 and 1992.

This DMS/SRP system uses microcomputer based low-cost image analysis software which interfaces with data captured from the multispectral CCD camera package. The system installation is suitable for most general aviation light aircraft with camera ports. The hardware is mostly standard, commercially available, low-cost components and, when configured for oil detection, the imaging system will use a cluster of three industrial video cameras. CCD field data can be recorded and stored on rewritable disks. The frame grabbing board in the portable microprocessor can also be programmed to direct individual frames for analysis and display in near real-time. Aircraft heading, ground speed, coordinate positional information and altitude can be read continuously from the aircraft's GPS and recorded onto a time tagged moving map file for future reference and target area calculations. This system is generally capable of providing near real-time identification and monitoring of accidental and chronic, unaltered and weathered hydrocarbon pollution (as well as other environmental hazards).

Remote sensing has been widely identified as being of considerable importance to most areas of environmental management. Most existing airborne multispectral systems are few in number and expensive. In addition they require more expensive, relatively larger aircraft then are generally used for conventional photo survey. In addition, they are mostly data collection systems that do not normally have on-board analytical capability.

Castleman (1979) briefly outlined some of the history of the use of vidicon cameras in the NASA space programme. With the failure of the RBV system in Landsat 1 the multispectral sensor emphasis switched to line imaging systems and little research continued with video cameras for remote sensing. In Canada Vlcek (Vlcek et. al., 1985) pioneered the use of video cameras for low cost multispectral remote sensing. This work was subsequently followed up by Roberts (Roberts, 1995; Roberts and Anderson, 1999; Roberts et. al., 1998) and King (1995). In the United States Meisner (1986) summarized a line of research on MSV systems involving Everitt, Escobar, Nixon, Richardson and others. More recently, researchers have used video for remote sensing but most applications have used composite cameras and analog recording. Exceptions include airborne digital systems recording on DAT tape and developed from concepts based upon the system described here (e.g. Benkelman et. al., 1990) and digital cameras (e.g. King, 1995).

Interest has principally remained focused upon line imaging systems. In Canada, the CASI instrument developed by Itres Research (Babey and Anger, 1989) has become popular as a relatively low cost alternative to other electro optical line imaging systems (Franklin et. al., 1991). This system has been more or less operational for a number of years but still suffers from geometric distortion problems which have led to low altitude constraints. The CASI system is not normally operated below 1,500 m. This, of course, reduces spatial resolution, although the use of longer focal length lenses permits up to 1 metre pixel resolution. The system is still relatively expensive ($300,000+) in comparison to DMS and, although it does have narrow band spectral capability (1.8nm), it does not produce spectrally overlapping image bands (an important theoretical consideration regarding white region normalization and some related band comparison procedures).

An alternative form of CCD based imaging spectrometer to the Itres CASI has been developed by Sun and Anderson (1993) at the University of Dundee. This system provides approximately 10nm bandwidth spectral data across the CCD spectrum (400nm to 1000nm). The approach is radically different than the CASI. A CCD video camera is used with a variable interference filter fixed in front of the sensor surface. This provides a "rainbow" image of the ground varying across the image from 400nm at the front to 700nm at the rear (visible VIFIS) and/or 700nm to 1000nm for the near infrared version. For practical and cost considerations these VIFIS sensors require separate cameras for visible and NIR. The images are tape recorded and integrated into spectral band images in the laboratory after data acquisition (although the original taped images can be used to provide spectral profiles). These VIFIS cameras are very low cost (they can be assembled for about $3,000) and the overall system is approximately an order of magnitude ($30,000) less expensive than most commercially available imaging spectrometers. In addition, because it is a two dimensional imaging system, it is also an easier system to geometrically correct for changes in aircraft flight parameters between the same spectral lines on the integrated "single band" images.

The DMS system outlined here is an inexpensive, multispectral, intelligent image acquisition and analysis system, with real-time on-board analytical capability, that can be used in most light general aviation aircraft. Real-time processing of multispectral video data and aircraft positional information will permit this intelligent system to automatically sense specified preset anomalies, such as oil on water, and provide continuous locational and area data to resource management teams.

4. TECHNICAL DETAILS

4.1 Objectives

The principal objective was to develop a intelligent airborne multispectral image acquisition and analysis system for environmental remote sensing. Important criteria for this system were: (i) low cost; (ii) user friendly; (iii) adaptable for light aircraft; (iv) full functioned image analysis and digital photogrammetric capability for laboratory use.

The present system is based upon a pentium portable microprocessor with image capture and display boards, specially developed image analysis software, a variety of CCD and photographic cameras and encoding aircraft navigation instruments.

During the first phases of development: (i) the hardware was assembled and interfaced; (ii) the basic operational software was developed, and; (iii) the system was field tested for its performance capabilities with water quality analysis and the field identification of small coastal petroleum slicks in the general Vancouver area. Future development will involve: (i) improved real time capability (i.e. radio transmission of airborne data to control centers), and; (ii) development of further intelligent capabilities in environmental remote sensing for forestry, agriculture, wildlife habitats and environmental hazards (e.g.. floods, forest fires).

<u>Hardware/Software Configuration</u>:

Pentium microprocessor
Pentium notebook microprocessor
image processing software
softcopy workstation software
GIS software
dual-line colour monitor
32 bit image capture card
rewritable high density drive
3 CCD (400-900nm) monochromatic progressive scan cameras
Newvicon (350-900nm) monochromatic video camera
waveform monitor
six channel video switch
2 35mm (Nikon F250) reconnaissance cameras
2 70mm Vinten reconnaissance cameras
1 International Imaging System (IIS) 24cm multispectral camera
GPS moving map coordinate navigation system
encoding altimeter
equipment and camera mounts for aircraft
power converters

Suitable software routines continue to be developed to adapt the image processing software for use in a real time intelligent context. Routines are necessary for the following steps:

(1) capture of a timed sequence of simultaneous RGB video, VIFIS or progressive scan CCD images and their redirection from the 32 bit image capture card(s) to RAM and streamed recording to the high density drive;
(2) redirection of selected CCD images into the notebook microprocessor for image analysis system access;
(3) spectral analyses of the captured imagery;
(4) threshold criteria and system response for critical spectral values;
(5) housekeeping of analyzed imagery (discard and storage).

Initial intelligent development has been for the detection and subsequent analysis of petroleum slicks in coastal B.C. waters. This has involved the determination of the unique spectral characteristics of petroleum slicks (diesel, gasoline, bunker C, crude and waste oil) as distinct from other common water signatures (e.g.. suspended sediment, submerged and surface vegetation, bottom reflectance, waves, foam, boats, buoys, rocks and small islands). An initial procedure has been developed from existing knowledge and experience with such water related targets. These procedures have been field tested in a series of airborne experimental missions to: (i) locate small slicks in the Vancouver area; (ii) image targets of opportunity (i.e. spills identified by the Department of Environment's Environmental Protection Branch in West Vancouver), and; (iii) undertake comparison studies with various "noise" targets from other common water signatures. Throughout this experimental phase there has been some continuing refinement of the analytical criteria for intelligent detection.

These field experiments were conducted using the Simon Fraser University (SFU) Remote Sensing Laboratory's aircraft and the integrated SFU DMS/SRP system as described here. A marketable system would probably consist of a slightly different selection of components (cameras, recording devices and possibly some of the cards) and a different equipment/aircraft mounting configuration.

The principal anticipated problem area has been related to speed and efficiency of communication between the image capture card, the imagery storage device and the image processing software. This determines the speed of "real-time" intelligent decisions. Initially the problem has been solved by directing the captured imagery through the random access memory (RAM) to the high density drive and to a second microprocessor running the image processing software.

CONCLUSIONS

In general this intelligent DMS system is characterized by low cost ($50K), excellent radiometric resolution, good spectral resolution, good geometric accuracy, satisfactory spatial resolution and real time capability. The SAP system is also low cost ($50K), has adequate radiometric and spectral resolution, excellent photogrammetric accuracy, excellent spatial resolution and no real time capability. Commercially available imaging spectrometers are approximately an order of magnitude more expensive ($300K+), have satisfactory (potentially excellent) radiometric resolution, excellent spectral resolution, poor photogrammetric accuracy, moderate spatial resolution and real time capability.

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