

# AIRBORNE DATA ACQUISITION FOR INTERDISCIPLINARY RESEARCH AND EDUCATION

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## Abstract

This paper describes an Airborne Multi-Spectral Imaging System (AMIS) and the development of its system software. This system has been developed so as to be rapidly deployed in response to episodic events such as hurricanes and tropical storms which may occur year round in coastal zones. The system uses digital video cameras to provide high resolution images at a very high collection rate. The system is software controlled so as to provide a minimum distraction for the aircraft pilot by providing for the remote manipulation of the camera and the GPS receiver. The system is viable for many applications that require good resolution at low cost. Such applications include vegetation detection, oceanography, marine biology, and environmental coastal science analysis.

## Introduction

This paper describes an Airborne Multi-Spectral Imaging System (AMIS) that uses digital video cameras to provide high resolution images at a very high collection rate.[1,2] Software has been developed to control the camera and the GPS receiver components of the system. This software provides for the remote manipulation of various functions, including play, stop, and rewind. The system has many applications, including vegetation detection, oceanography, marine biology, and environmental coastal science analysis. Such applications have become increasingly common in recent years. While there are many multi-spectral Satellite Remote Sensors such as the LANDSAT MSS and LANDSAT TM, these systems offer only 30-meter spatial resolution

pixels. Another limitation of satellite sensors is that their temporal resolution is based on their orbital passes. AMIS offers an efficient solution that supplies excellent scientific information by providing near real-time high resolution images.

Texas A&M-Corpus Christi is located on Ward Island in Corpus Christi Bay. Hurricanes, tropical storms and other episodic events occur year round in the area. Our marine biologist, environmental scientist, and geologist colleagues of the Center for Coastal Studies often need to investigate and analyze the after effects of such events at near real time. The vendors of satellite images are often unable to meet the desired temporal and spatial resolution. In addition to being costly, commercial airborne remote sensing systems have to be deployed at the scene of investigation as soon as possible for data to be useful for studies and research. The remainder of this paper describes AMIS and the software that operates and controls its major components. The paper also presents test results that clearly demonstrate the capabilities of the system.

## System Hardware

The prototype consists of a Sony DCR-PC1 MiniDV handycam. The Sony DCR-PC1 has the following specifications:

- Imaging Device: Single ¼” CCD 680k Pixels
- Lens: 10x, variable 35mm – 420mm
- Shutter Speed: 1/60 – 1/4000
- DV In/Out (IEEE 1394 interface)
- S-Video Out
- Power Consumption: 3.4 W/4.5W.

Our prototype configuration, like the airborne remote sensing system at Ohio State University or the digital camera system at the University of Calgary, required data to be recorded and post-processed. Although this solution delays the availability of results, it produces good spatial results, for example, 2-meter positional accuracy and 3-meter accuracy in height.[4] Recently, a small-format aerial photographic system was used in combination with lower resolution images for rectification.[5] Compared to existing scanned products, the digital frame array offers a pixel resolution of around 4.5  $\mu\text{m}$ .

The system was mounted in the inspection hole of a Cessna 172RG (Courtesy Lanmon Aerial Photography Inc.) The camera was suspended within the hole by means of a mounting ring and arm attachment. We used aluminum alloy as the material for the mount ring. Under the mount ring, there is a rubber ring to dampen the vibration of the camera. There is an arm connection to the ring, which is screwed into the tripod mount socket on the digital video camera. The arm consists of a simple 90° angle made from a one-inch wide strip of aluminum alloy that was connected to the mount ring with two screws. The arm was constructed by drilling two holes, one for the digital video camera fastening screw and the other for the tripod mounting pin socket. The purpose of the mounting pin socket was to keep the video camera from rotating about the fastening screw as well as to eliminate some of the vibration. The mounting pin was achieved by expanding an aluminum rivet through the second hole drilled through the arm.

To prevent wind from entering the aircraft around the sides of the video camera, a hood was made to fit over the lens. The hood extended from the lens of the camera to the skin of the aircraft and was constructed from foam-rubber material. This foam-rubber hood serves two purposes; it eliminates the wind and exhaust from entering the aircraft around the video camera, as well as, further reduces the vibration of the mounted system. The hood was then

secured within the aircraft with a modified inspection cover. A hole ( $\phi = 3.0$  in.) was cut in the center of the original inspection cover to allow the camera lens to record the ground below while still securing the contents of the video camera setup.

The global positioning system is a Garmin GPS III Plus receiver is used for navigation. A Leica SR 530 geodetic receiver is used to record the latitude, longitude, and altitude (from the NMEA-0183 protocol string) of the acquired images. The GPS receiver is connected to the COM port of the system computer. The features of the GPS receiver are as follows:

- Coordinates: Lat/Lon, UTM/UPS, MGRS, Loran TDs.
- Receiver: Differential-ready 12 parallel channel receiver continuously tracks and uses up to twelve satellites to compute and update a position.
- Update rate: 10 Hz
- Accuracy: Position: 15 meters, Velocity: 0.1 knot RMS steady state or 0.01 meter in Real-time mode

### **Software Development**

Our prototype software was developed using the programming language Delphi. Delphi was chosen because it is very efficient and easy to use to develop graphical user interface (GUI) applications. It is an object-oriented visual programming language based on the Pascal programming language. It combines the user-friendliness of Visual Basic with the control and speed of C++. Delphi is sometimes called a rapid application development (RAD) tool since it reduces the complicated task of programming Windows applications to the handling of "objects" in a visual environment. It allows users to visually design (by using drag-n-drop) dialog and even whole applications. The toolbar of the main window in the integrated development environment (IDE) has many pre-defined GUI components to use. These components can be used to create a complete graphical application. Delphi also supports

ActiveX programming and ActiveX controls. ActiveX controls are re-usable component program objects. These components can be used to add specialized functionality, such as animation or pop-up menus, to Web pages, desktop applications, and software development tools. ActiveX controls play a major part in the video acquisition portion of the AMIS software.

The camera and the GPS receiver are both controlled by software. The software reads and records the GPS co-ordinates and the corresponding time. The software incorporates ActiveX controls to enable easy access to the imaging devices connected to the system's control computer. ActiveX Controls also provides a RAD environment. We are using this tool to manipulate various functions such as play, stop, rewind and other functions remotely. We are also using ActiveX controls to play the frames in a video window in the system's GUI. The user can then record the video onto the hard disk drive. IEEE-1394 (firewire) interface provides speeds up to 400 Mbps to transfer digital video. The other functions the ActiveX controls provide is saving bitmap images of frames which are being either played or recorded.

The prototype AMIS software had two main functions: 1. Video Acquisition, and 2. GPS Coordinates Acquisition. The control GUI is divided into two sections; a Video Window and a GPS Window, as shown in Fig. 1. The video window has controls for the imaging devices and the display and recording of video. The GPS window provides interfaces to control the GPS receiver and log the GPS data.

### Video Acquisition

The goal is to acquire aerial images and rectify them. Rectification means orienting the images in their true geographical coordinates. If a set of aerial images is rectified, then a complete continuous photograph that represents a geographical area can be created.

To manually georectify an aerial image, aerial photographs are collected using both a large format 9''x 9'' black and white film and a small format 35mm color slide film from an airborne station. The film slides are then developed and scanned into a digital format. Then to georectify the image it is loaded into GIS software such as ESRI ArcMap. Using a set of known ground points as a guide, the image is then georectified

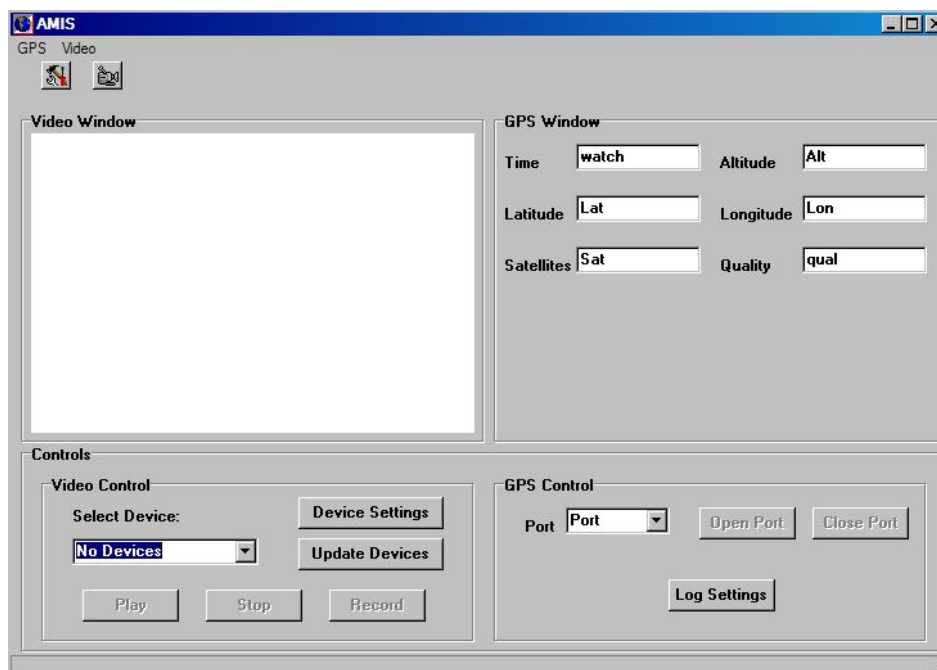


Fig. 1. Software control of camera and GPS.

by scaling and rotating the image based on the known points using GIS software. This process gives accurate results but is time consuming.

Instead of grabbing the aerial photographs or frames individually, our system acquires aerial video and grab the frames from the video after acquisition. We then use ArcMap to post-process the frames from video into tiff (tagged image file) format.

The camcorder is directly connected to the control computer via the IEEE 1394 Firewire port.[3] Firewire ensures fast data rates and can handle transfer of DV quality video easily. The video is acquired directly to the hard-disk drive of the computer. Up to one hour of video can be stored on a single 40 GB hard drive. Typically, 4 minutes of DV quality video takes approximately 4 GB disk space. AMIS software uses IC Imaging Control, an ActiveX library for acquiring digital video. Features of IC imaging Control include:

- ActiveX and C++ class library.
- Capture video from USB, Firewire, PCI, PC-Card and DV devices.
- Build one application that runs on PCs with PCI cards and also on standard laptop hardware with no modification.
- Switch between video sources on-the-fly.
- Full frame at full resolution live video preview (even on laptops).
- Single frame and image sequence capture.
- Video codec support to write to .AVI.

### **GPS Acquisition**

The GPS coordinates and video are synchronized. This is achieved by simultaneously recording the start time and end time of the video and those of the GPS coordinates. Synchronization is done using flat-

file approach. This file provides the frame and the exact GPS co-ordinates for a given time.

GPS acquisition begins at the same time as video acquisition. The physical offset (distance) between the GPS receiver and the camera is minimal, however we correct for the offset in the GPS system. The GPS information is stored in tiff world file format. A tiff world file is a plain text text file accompanied with a tiff image file. The details of this file format are discussed below. The GPS receiver is attached to the serial port or COM port of the computer. The GPS information is read through this port. There are many types of GPS strings; some are generic while others are proprietary that give position information. The software for AMIS uses the NMEA-0183 GPS strings to extract the position information. The NMEA-0183 string is a string made available at short intervals. These strings can be read and parsed from the COM port where the receiver is connected. The interval at which the GPS information is provided depends on the receiver. Inexpensive hand-held receivers offer information at an interval of 2 seconds whereas geodetic receiver systems offer GPS position information every 1/10<sup>th</sup> of a second.

The NMEA-0183 is a standard protocol used by GPS receivers to transmit data. The NMEA output is EIA-422A but for most purposes it is RS-232 compatible. The serial port settings have to be set before the GPS can transmit the data through it. The baud-rate is set at 4800 bps, with 8 data bits, no parity and one stop bit. NMEA sentences (data) are pure ASCII. There are many NMEA sentences which reveal the position data along with some other information. The format of each of these NMEA sentences is the same. Every NMEA sentence begins with a dollar sign (\$) and ends with a carriage return – line feed <cr><lf>. The data is comma delimited. All commas must be included as they act as markers. This is important because some systems do not send all fields. Even if they do not send all fields, they should provide commas indicating the blank fields in the NMEA sentence. In some cases, the NMEA sentence has a checksum added at the last field.

In some cases the check sum field is mandatory. The \$ sign at the beginning of the NMEA sentence is followed by address field in the aacc format. Here, the aa is device id. GP is used to identify data. The ccc is known as sentence formatter or the sentence name. Hence, if the NMEA sentence begins with \$GPGGA, the NMEA string contains GPS data and the sentence name is GGA. Though there are many NMEA strings that identify and transmit GPS data, the software for AMIS uses the GGA sentence to extract the position information. Elements of a GPGGA NMEA string appear as follows (separated by commas).

```
$GPGGA,145121.999,5121.2199,N,00032.5133,E,1,06,2.1,175.9,M,,,,,0000*0A
```

- 1 = UTC of Position
- 2 = Latitude
- 3 = N or S
- 4 = Longitude
- 5 = E or W
- 6 = GPS quality indicator (0=invalid; 1=GPS fix; 2=Diff. GPS fix)
- 7 = Number of satellites in use [not those in view]
- 8 = Horizontal dilution of position
- 9 = Antenna altitude above/below mean sea level (geoid)
- 10 = Meters (Antenna height unit)
- 11 = Geoidal separation
- 12 = Meters (Units of geoidal separation)
- 13 = Age in seconds since last update from diff. reference station
- 14 = Diff. reference station ID#
- 15 = Checksum

The software reads the NMEA string from the COM port and parses the GPGGA string to get the time, latitude, longitude, and altitude information and logs this information to a text file in the tiff world file format. Tiff world files (.tfw) are simple text files which contain metadata for a tiff file with the same name. An image.tif file, for example, will have an accompanying tiff world file called image.tfw. Many GIS applications ArcInfo, ArcGIS,

MapInfo support Tiff file (.tiff) format. The following is a sample tiff world file:

```
2.0044
0.0000
0.0000
-2.0044
441794.4342
50194142.4520
```

The first and fourth numbers in the file specify the pixel size of the accompanying tiff file in the X-direction and Y-direction respectively. The second and third numbers are the rotation in X and Y direction, respectively. The last two numbers in the file are the true X and Y coordinates of the accompanying tiff image file. The AMIS software computes the above mentioned six parameters for the tiff world file and stores them along with time information from the GPGGA sentence. The significance of this is that when a frame of video is captured, we already know the time at which the frame was captured and hence we would be able to geo-rectify the image/frame very easily using the tiff world file parameters. Some of the tiff world file parameters are obtained directly from the GPGGA string but others have to be computed. The following discussion specifies the methodology to compute all the six parameters of the tiff world file.

Every image captured by the software will have a world file (.tiff) linked to it which will specify the parameters required to geo-rectify the image. The format of the tiff world file is as follows:

- a -> Pixel size in X direction
- d -> Rotation in X direction
- b -> Rotation in Y direction
- e -> Pixel size in Y direction
- c -> X co-ordinate of the image
- f -> Y co-ordinate of the image

Values of c and f can be obtained directly by latitude and longitude information. Hence the shift information is directly obtained by the

GPS. As for the rotation parameters b and e, they can be obtained by tilt sensors, which will record the tilt and the heading information. If we wish to keep this parameter zero, we need to ignore the nominal tilt of the airplane.

### Automating The Post Processing

The post processing or georectifying process as described above is accurate, but is very time consuming. We have now developed software to automate this process. As noted above a tiff world file is created along with each image file. The contents of this world file will look something like this:

```
20.17541308822119
0.0000000000000000
0.0000000000000000
-20.17541308822119
424178.11472601280548
4313415.90726399607956
```

All of these six parameters can be used to georectify the image. By incorporating the GPS receiver, some of the parameters can be calculated. To calculate the scale of the image in the X and Y directions we use the height information (altitude) obtained from the GPS. The following equation shows the relation of the height (altitude) with the scale factor:

$$1 / \text{s.f.} = \text{f.l.} / H = d / D$$

where,

s.f. = scale factor

f.l. = focal length of camera

H = height of the image from Mean sea level

D = size of the image

D = actual ground coverage represented by the image.

Notice that the height (H) is the height from mean sea level. However, the height from the ground or the terrain is required. If the terrain is flat and not changing much, then an approximate value can be assumed by the contour map available. This distance can then be

deducted from the height (H) obtained to give the height of the image from above the ground or terrain. Hence we can also find the scale of the image in X and Y direction using the equation above. Therefore, by using the GPS data and computing the parameters of the tiff world file, we can have the tiff world file for any frame grabbed from the acquired video.

To perform an image-to-world transformation our software uses a six-parameter affine transformation in the form of:

$$x1 = Ax + By + C$$

$$y1 = Dx + Ey + F$$

where:

x1 = calculated x-coordinate of the pixel on the map

y1 = calculated y-coordinate of the pixel on the map

x = column number of a pixel in the image

y = row number of a pixel in the image

A = x-scale; dimension of a pixel in map units in x direction

B, D = rotation terms

C, F = translation terms; x,y map coordinates of the center of the upper-left pixel

E = negative of y-scale; dimension of a pixel in map units in y direction

Note The y-scale (E) is negative because the origins of an image and a geographic coordinate system are different. The origin of an image is located in the upper-left corner, whereas the origin of the map coordinate system is located in the lower-left corner. Row values in the image increase from the origin downward, while y-coordinate values in the map increase from the origin upward.[6]

### System Testing

The first test flight was completed on March 1, 2002 by taking aerial pictures of the A&M-CC campus and the immediate coastal area. A number of ground control points were set on

campus. A LCD screen (an 8 mm Sony Digital Player) mounted on the pilot's control allowed the pilot to see what the video camera was viewing. The LCD screen and the video camera were connected through an S-video cable. The images were recorded on both the digital videotape and by utilizing Pinnacle Studio DV version 7 software on a laptop with an Adaptec Inc. IEEE 1394 PCMCIA interface card. Figure 2 shows one of the recorded digital pictures. The aerial images of the prototype system have a 30 cm resolution for a flying height of 1500 feet. These results meet the needs of the scientific staff at A&M-CC.



Fig. 2. Corpus Christi Texas urban area.

On 12<sup>th</sup> July 2002, a second test flight was conducted over the Chapman Ranch located in Nueces, Kleberg, and King counties of south Texas. The purpose of the flight was to determine the quality of the system's vegetation detection as well as record the flooding of the Nueces River. For vegetation detection, we flew over the Chapman ranch at lower altitude (3000 ft.) before capturing the Nueces River flooding at 12,500 feet. Some of the images were processed and analyzed. Images were rectified using existing Digital Ortho Quarter Quadrangle images from the US Geological Survey. Next, the images were enhanced to improve convolution, edge enhancement, and contrast utilizing a spectral pass filter. The final production of an enhanced image, where features are clearly visible, is seen in Figure 3. The next objective was to replace visual colors

with a classified pattern. An unsupervised classification method was used to determine the natural breaks between the shapes, sizes and spectral signature. Figure 4 shows a binary thematic map of the spectral pattern. The data classification is stretched between the two values representing amount of saturation. Here, land and water can be separated. The objective of the development of the classified map is to (i) identify a flooded area and its boundaries, and (ii) assign land ownership to flooded area.



Fig. 3. Digital image of Nueces river flooding.

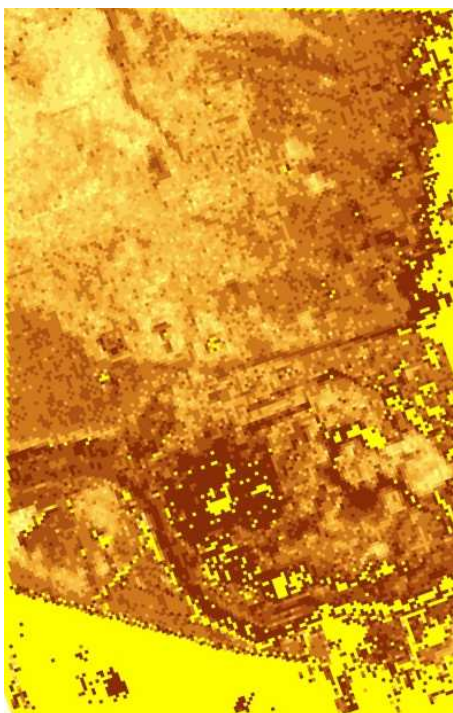


Fig. 4. Classified image of flooded area.

### **Student Participation**

Students have been involved in this project from its inception. The first student to work on AMIS was a graduate student in computer science. He was recruited to the project because he had an electrical engineering undergraduate degree. His knowledge of both hardware and software was very valuable for the project. He was responsible for overall system development, including specifications, ordering parts, software development, construction, and testing. We then hired two undergraduates to assist our graduate student, a female Hispanic majoring in electronic engineering technology and a male mechanical engineering technology student. Another female GIS major was hired to help with system installation and testing. A second female Hispanic geographic information sciences undergraduate student as well as a Hispanic male and two anglo males majoring in geomatics were hired to map out georeferencing and ground control points for testing. These students managed the development and implementation to the first test.

As students graduated we hired two additional male students a graduate computer science major and an undergraduate geomatics major. The graduate computer science student wrote all of the automatic post-processing software. Two of the graduate students involved used their work in this project for their graduate projects, while one of the undergraduates was hired by our aerial photography partners on the basis of her work on the project.

### **Conclusion**

This paper presented an Airborne Multi-Spectral Imaging System that uses digital cameras to provide high resolution images at very high rates. The software controls the camera and the GPS receiver and allows the remote manipulation of various functions, including play, stop, and rewind. The GPS coordinates and the corresponding time are simultaneously recorded and the images are automatically geo-rectified. The system is viable for many applications that require good resolution at low cost. Test results yielded a pixel size of approximately 30 cm, at an average flying height of 1500 ft. These results meet the spatial, spectral, and temporal resolution for coastal study applications. Test results also show that a digital video image could be used to create classified maps that clearly identify land boundaries of flooded areas.

### **Acknowledgements**

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### **Biographical Information**

Carl Steidley is Professor of Computer Science and Chair of Computing and Mathematical Sciences. His interests are in the applications of artificial intelligence, real-time computing, and robotics. He has had research appointments at NASA Ames Research Center, Oak Ridge National Laboratories, and Electro Scientific Industries in Portland, Oregon. Steidley received his Ph.D. from the University of Oregon.

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Gary Jeffress is Professor of Geographic Information Science and Director of the Division of Nearshore Research. His interests are in the development of real-time observation systems and their integration with geographic information systems. He is currently president of the Geographic and Land Information Society. Jeffress is a Registered Professional Land Surveyor in Texas and received his Ph.D. from the University of Maine.

Rahul Kulkarni is Network Manager-I in Computing and Mathematical Sciences at A&M – Corpus Christi. He has a MS degree in Computer Science from A&M – Corpus Christi. While doing his Masters degree, Rahul worked as Research Assistant researching in Aerial Photography and design and development of Airborne Multi-spectral Imaging System. Rahul also holds a Bachelors degree in Electrical Engineering from University of Mumbai, India.