INL/CON-05-00235
PREPRINT

Small UAV-Acquired, High-Resolution, Georeferenced Still Imagery

Wildlife Society 12th Annual Conference

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September 2005

The INL is a
U.S. Department of Energy
National Laboratory
operated by
Battelle Energy Alliance

Idaho National Laboratory

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Abstract: Currently, small Unmanned Aerial Vehicles (UAVs) are primarily used for capturing and down-linking real-time video. To date, their role as a low-cost airborne platform for capturing high-resolution, georeferenced still imagery has not been fully utilized. On-going work within the Unmanned Vehicle Systems Program at the Idaho National Laboratory (INL) is attempting to exploit this small UAV-acquired, still imagery potential. Initially, a UAV-based still imagery work flow model was developed that includes initial UAV mission planning, sensor selection, UAV/sensor integration, and imagery collection, processing, and analysis. Components to support each stage of the work flow are also being developed. Critical to use of acquired still imagery is the ability to detect changes between images of the same area over time. To enhance the analysts' change detection ability, a UAV-specific, GIS-based change detection system called *SADI* or System for Analyzing Differences in Imagery is under development. This paper will discuss the associated challenges and approaches to collecting still imagery with small UAVs. Additionally, specific components of the developed work flow system

will be described and graphically illustrated using varied examples of small UAV-acquired still imagery.

Introduction:

Geospatial information is an essential part of the national and international infrastructure in our information-driven society. It is estimated that some 80 percent of our daily decisions rely on some type of geospatial information (Heipke 2004). Imagery and other data collected from remote sensing systems play a significant role in geospatial data acquisition used to generate new databases and to update existing databases. These data allow people to develop a strong, clear understanding of where they are physically, the potential impact of their decisions, and to identify changes in the environment over time, which are all aspects of situational awareness (Endsley, 1995a; 1995b). Critical to the development of situational awareness is the ability to identify very subtle changes in the environment over time through differences in images, a process called change detection. In order to fully utilize UAV-acquired, remotely sensed imagery for applications such as change detection or situational awareness, the imagery must be geometrically corrected and registered to a map projection. This process is referred to as georeferencing which requires the scaling, rotating, and translating from the image coordinate system to the map coordinate system (Mather 1999, Jensen 1996). Traditional georeferencing techniques, such as aerial triangulation, “image-to-map”, and “image-to-image”, incorporate the use of ground control points (GCPs) to register the imagery (Figure 1). However there are a number of issues with the use of GCPs, including the high cost associated with collection of GCPs and the fact that for many missions performed by UAVs, GCPs are either not available or are impossible to obtain. In addition, the small footprint of low-altitude UAV acquired imagery complicates the georeferencing process because such imagery lacks distinguishable GCPs, especially for single photo missions. Direct georeferencing is a promising concept that incorporates a predefined sensor model (interior orientation) and a GPS augmented inertial measurement system to measure the sensors' exterior orientation at the moment of exposure. By eliminating the need for ground-based measurements, these methods allow sensor data to be obtained and utilized quickly, safely, and cheaply. Operational systems being used in the photogrammetry and remote sensing industry address direct georeferencing concepts (Applanix Corporation). However, these systems and their hardware have been designed for larger, manned aircraft with much larger payload capacities than the UAVs currently being used at the Idaho National Laboratory (INL).

Figure 1: Georeferenced mosaic of the UAV runway at the INL taken from 8mp Canon 20D (Image-to-Image Registration).

The Unmanned Vehicle System Program at INL has developed a comprehensive system model for collecting high-resolution, georeferenced frame imagery from small

UAV platforms to. The components identified to support this system perspective include: UAV mission planning; sensor selection; UAV/sensor integration; imagery collection and processing; and analysis. As depicted in Figure 2, the workflow model offers the potential to integrate both system architecture and software solutions to address diverse imagery-related needs, including change detection.

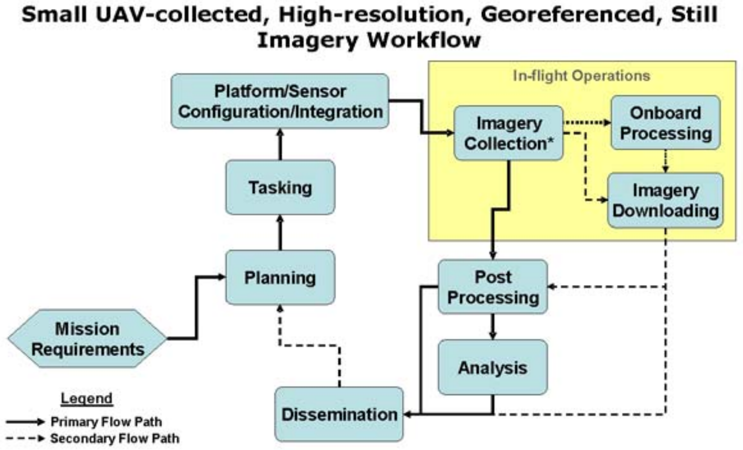

Figure 2. The INL-proposed workflow model for collecting high-resolution georeferenced still imagery.

Mission Requirements and Planning:

The initial step for any successful remote sensing mission is to determine the specific objectives and requirements for the flight. This requires determining who the users are, what they plan on using the imagery for, where and when does the imagery need to be acquired, level of detail required (accuracy and resolution), and what does the final product need to look like (O'Neil and Hill 2000, Jensen 1996). For a change detection mission, additional consideration must be given to: time of day of image acquisition; look angle; atmospheric conditions (i.e., cloud cover/shadowing); environmental conditions (soil moisture, phenology); and sensor characteristics, all of which can obscure "real" changes through introduction of artifactual differences (Jensen 1996). Once mission objectives have been determined, the appropriate platform and sensor can be tasked to meet user needs and reduce image artifacts, after which technical specifications can be determined such as flight altitude, focal length, resolving power (photo scale), overlap and sidelap, and number of flight lines. GIS-based flight planning tools provide a powerful platform to optimize and visualize UAV remote sensing missions and help to reduce image artifacts and avoid many common mistakes that occur during the planning process. For example, by incorporating the appropriate DEM (Digital Elevation Model), flight heights can be calculated automatically to maintain the desired photo scale and avoid gaps in wide area surveys.

UAV Platforms and Sensor Integration:

Direct referencing high-resolution still imagery from small UAVs requires that a global positioning system and inertial measurement unit be integrated with an imaging sensor to acquire exterior orientation parameters at the time of image exposure (Figure 2). Special consideration must be given to sensor placement and synchronization, which is extremely important for a direct referencing mission that requires high positional accuracy (Mostafa et al. 2001, Skaloud 1999, Grejner-Brzezinska 1999).

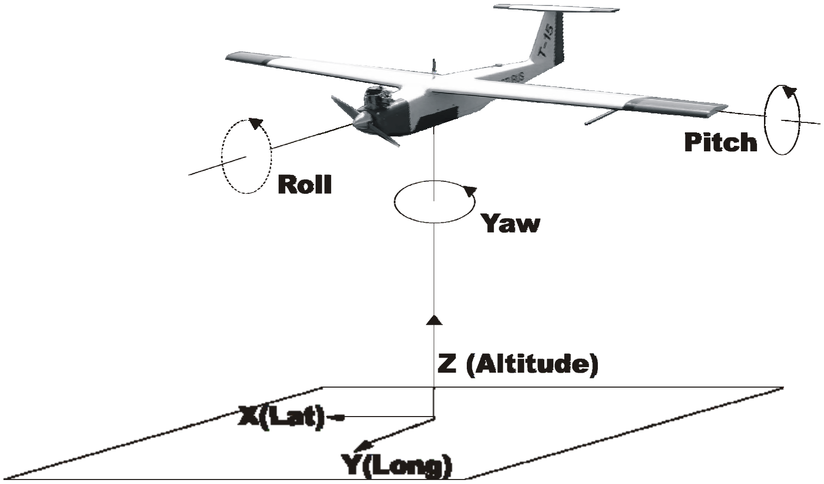

Figure 2. Exterior orientation measured by on-board GPS/IMU.

Sensor placement should be driven by two objectives: 1) isolating the inertial measurement unit (IMU)from the airframe vibrations, avoiding differential movements and 2) minimizing boresight misalignment, that is, any offsets between the GPS antenna, IMU, and the perspective center of the imaging sensor (Skaloud 1999). Due to the inherently small payload bay of small UAVs, these offsets may be minor; however they must be quantified to obtain a high-level of positional accuracy. Synchronization refers to referencing the individual sensor components to a common clock and input trigger. Even small errors associated with improper synchronization can have a serious impact on the direct referencing process and mission success (e.g., a UAV traveling at 60 knots with a 1 second synchronization error would result in 25m of along track error, possibly missing the intended target entirely). These decisions are further complicated by the limited payload capacity (size and weight) of class II/III UAVs (typically 10-20 lbs) and on-board power restrictions.

Camera Calibration:

Digital frame cameras currently are receiving great interest from the remote sensing and aerial surveying communities due to their relatively low costs. However, most of these cameras are not manufactured metric devices; therefore, if they are to be used in precision mapping applications it is crucial that they are repeatedly calibrated in order to assess current interior orientation parameters (Grejner-Brzezinska 1999). The interior orientation parameters (sensor model) consist of principle point offset, focal length, and lens geometric distortion characteristics. There are two types of distortion: 1) radial distortion, which is symmetric from the principle point (pincushion and barrel distortion, see Figure 3), and 2) tangential or decentering distortions.

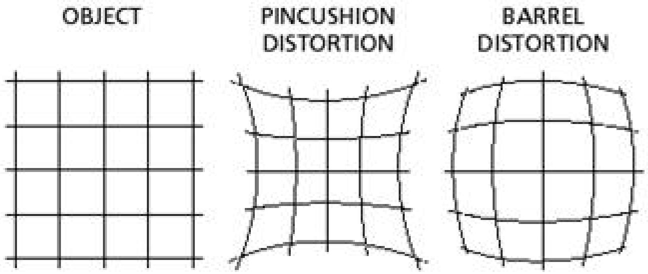

Figure 3: Types of Radial Lens Distortion

These parameters describe the camera projection system. Correcting image distortions caused by sensor optics has been widely studied since the inception of aerial photography and is necessary for accurate direct georeferencing (Clarke and Fryer 1998, Jensen 2000, Grejner-Brzezinska, 1999). Interior orientation parameters can be obtained by acquiring a series of convergent images of an accurate 3-dimensional control field (such as shown in Figure 4).

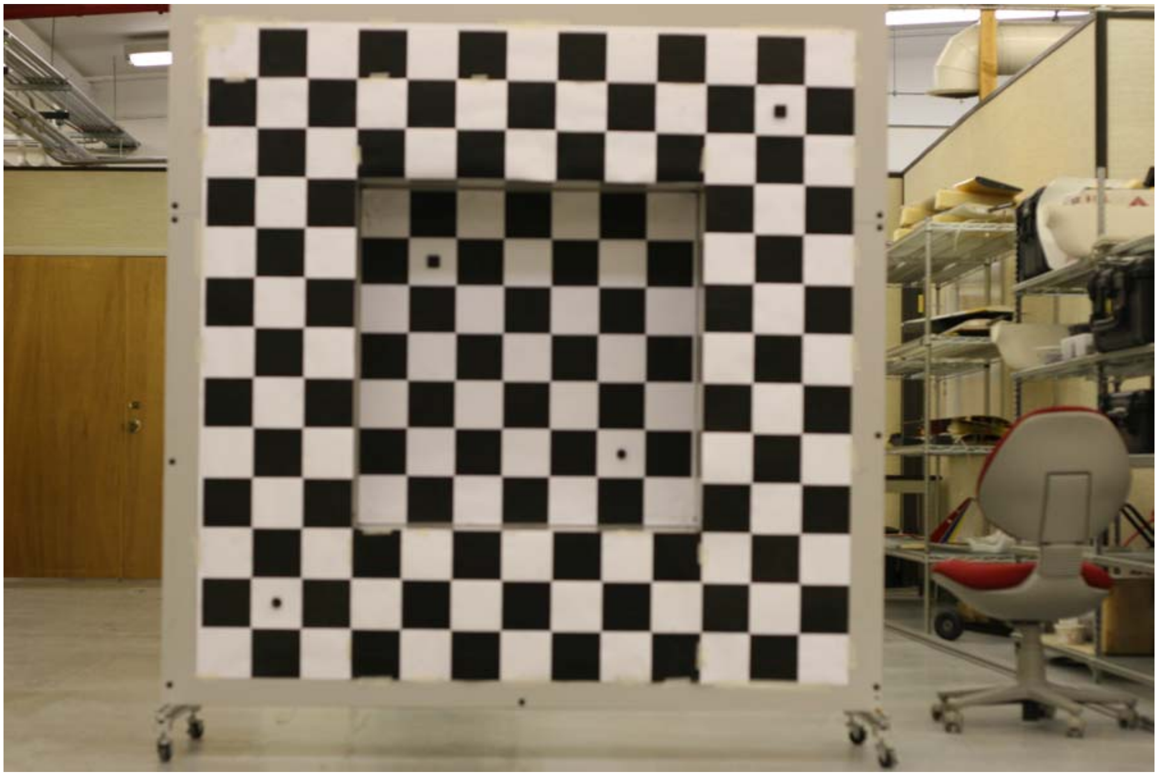

Figure 4: 3-Dimensional Control Field for retrieval of Interior Orientation Parameters.

Direct Georeferencing:

Direct georeferencing is the process of registering an image frame to a map coordinate system through direct measurement of the image exterior orientation parameters by a GPS (Global Positioning System) and IMU (Inertial Measurement Unit) at the moment of exposure. Such direct georeferencing further incorporates a predefined model of the sensor's interior orientation parameters. These parameters include location of the image sensor relative to a map coordinate system (x, y, z) and its perspective orientation (i.e., pitch, yaw, and roll) around that point (Kocaman 2003, Skaloud 1999). The model for transforming between the image coordinate system and map coordinate system, including correction for boresight misalignment, is presented in equation 1 (Grejner-Brzezinska, 1999):

Equation 1:

$$Mr_{m,i} = s^2 \cdot R^{M}_{BINS} \cdot dR^{BINS}_{C} \cdot M_{\omega} \cdot \left(dR^{BINS}_{C}\right)^{T} \cdot \left(R^{M}_{BINS}\right)^{T} + R^{M}_{BINS} \cdot M_{Offset} \cdot \left(R^{M}_{BINS}\right)^{T} \quad (1)$$

where:

$Mr_{m,i}$ – ground position covariance matrix
$r_{c,j}$ - image coordinates of the object in camera frame C
R^{BINS}_{C} - boresight matrix between INS body and camera frame C
R^{M}_{BINS} - rotation matrix between body and mapping frames
R^{BINS}_{C} - boresight matrix between INS body and camera frame C
M_{ω}, M_{offset} - diagonal covariance matrices of boresight angles and offsets, respectively
dR^{BINS}_{C} - partial derivative of $R^{BINS}_{C} \cdot r_{c,j}$ with respect to the boresight angles
s – scaling factor

Direct referencing technologies are currently being evaluated and initial results indicate that direct georeferencing provides an ideal solution for georeferencing high resolution still imagery for many applications; however, initial results suggest that it will not provide the positional accuracies needed for change detection applications. To overcome this, direct georeferencing will be used to constrain the search space for a high performance image registration routine. This routine aligns images to within a fraction of a pixel to compensate for differences in camera angle, altitude, and focal length using similarity measures, such as spatial cross-correlation.

Image Analysis:

Much of our imagery analysis at INL involves change detection. Change detection is the process of comparing historical imagery with new imagery to determine if there are any subtle, dramatic, or significant man-made or natural changes (Jensen, 2000). The Idaho National Laboratory has developed a computer software application, called the Change Detection System (CDS), which helps the user identify changes in objects, scenes or virtually any aspect of two images.

Change detection and its converse, "change blindness" (the inability of an analyst to see differences in images because of overwhelming amounts of information), have been the focus of considerable research efforts since the early 1950's. Much of this research has been embedded in psychophysical, visual and spatial cognition, and perceptual ability studies. Numerous experiments have shown that humans are not very good at detecting not only subtle changes in similar images, but major changes as well. Apparently our visual search strategies are typically both ineffective and inefficient.

Recent studies have concluded that a critical component for improving change detection is focusing the attention of the observer on a change signal or stimulus. A key technique in this regard is "priming", that is purposely drawing or focusing attention to a potential change condition. It should be further noted that once a change is detected, humans are very well equipped to identify and interpret the change. Indeed, it is argued that humans excel at this task much better than most mathematically derived pattern recognition algorithms. As such, we have developed a system that maximizes the human's ability to detect and identify "real" differences in images by using software to eliminate irrelevant differences between the image pairs.

CDS aligns two images by adjusting for differences in perspective and scale by employing a series of alignment algorithms. During the alignment process, the software identifies fiducial objects that occur in both images. A fiducial object is one that occurs in both images, is recognizable by the software, and is not confusable with other objects that may be nearby, thus allowing the object's centroid to serve as a tie point. The software defines multiple alignment iterations until the image alignment is optimized. The system user then rapidly flips between the two, now "identical" images. Differences between the two images appear as movement. The very strong human sensitivity to even very slight movement allows the user to quickly identify even the smallest differences. CDS combines the strengths of the computer to manipulate the images, the strong human capability to detect movement and the human ability to focus on substantive changes and ignore those that are inconsequential.

This system represents a significant advancement in the field of image analysis. We believe the process of image alignment can be modified to automatically align and display images by allowing CDS to use map cooridinates as fiducials in the initial image alignment process. A modified system could be configured for the comparison of images from sequential image libraries.

Conclusions:

Initial results indicate that the comprehensive workflow described above will be effective for collecting and georeferencing high resolution frame imagery in near real-time for a variety of UAV missions, including change detection. Currently, the major technological challenges are: 1) fitting required component technology into the relatively small payload bays; 2) reducing the payload weight (increasing flight time); and 3) minimizing the power demand of the sensor payloads. As the component technologies are refined and miniaturized, these challenges will be overcome and positional accuracies will improve.

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