SURVEY FLIGHT METHODS AND LOGISTICS

Tim McConnell

**Forest Pest Management, Missoula Field Office,
USDA Forest Service, Missoula, Montana 59807**

Purpose

The purpose of this talk is to briefly go over some aspects of survey flight methods and logistics necessary to conduct an aerial sketch mapping mission, as well as some things to consider before and during the actual survey. Additional information can be found in past publications on this subject.

Type of Survey to Be Conducted

Most traditional aerial surveys are considered overview or initial surveys. During some years, depending on severity of insect outbreaks, disease symptom manifestations, extreme weather effects, more extensive surveys may be warranted to address these specific conditions. The initial survey is done to obtain information on a broadscale. Even though most initial aerial detection surveys are quantitative, it should be remembered that the primary purpose is to detect disturbances across large areas. If it were to be more than that, a different map scale would be used, the survey would be flown at a slower speed, possibly a different type of aircraft would be used and a smaller area would be covered. For many land managers, the initial survey serves their needs under most situations.

To be an efficient senior aerial sketch mapper, it is important to keep in mind the type of survey being conducted. But since dollars are being spent for the aircraft, pilot, observer and ferry time, it is also important to record as much information as possible while the survey is occurring. With more and more users asking for aerial survey maps, the more important it has become for the sketchmapper to record as much information as is observed and is possible, realizing the limits of flying past the forest at 100 miles per hour with a small-scale map to record disturbances.

Survey Resource Limitations

Nature's limitation on the aerial survey is the biological window. Most conditions are only visible for a short period of time. One doesn't have all year to get the survey done. For most disturbances, it is during a 3-month period in the summer. Again, this isn't applicable to special surveys like southern pine beetle. Along with the time of year comes the time of day to fly survey. Light conditions are critical of good observations. Surveys should be conducted during the hours of the highest sun angle. Early or late day sun angle can be helpful in some areas that have an aspect facing the sun angle. For example, flying a long ridge that faces west late in the afternoon would work well, but you wouldn't want to fly that same area early in the morning.

The survey budget is an important aspect of how the survey is conducted. The budget dictates the amount of aircraft time to be used, as well as the number of observers and amount of time spent doing the survey.

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Many senior observers find themselves flying the survey much faster than was done several years before to get the survey flown within the allowable time and budget.

The time allowed to fly the survey is critical to how the survey is completed. If an observer has a month to fly one National Forest, there will be plenty of time to wait for ideal weather, only fly during peak sunlight hours and fly at a slow airspeed to ensure nothing is missed. Alas, these days the observer is challenged with doing as much as possible every day to complete the survey before the season ends.

The other resource challenge that faces every observer and program manager is that there are not enough trained, qualified observers to do the flying. Most Forest Service Regions had more qualified observers fifteen years ago than currently. The need to get the survey done each year is still exist, as well as the desire to have a quality product. In the Northern Region, currently, two observers cover approximately 26 to 28 million acres annually. Ten years ago the same area was surveyed by 5 observers. This is an added pressure to any observer to complete the survey within the bio-window and budget limitations.

Aircraft

Twin versus single engine

Most aerial surveys conducted in the western United States are flown in high wing, single engine airplanes because of their cost, availability and the need for only one observer. In the Pacific Northwest Region, where 90 per cent of the survey flying technique is grid or parallel line flying, high wing ,twin engine airplanes are predominately used. The twin engines are preferred for the weight and performance safety margin since most flights carry two observers, one pilot and frequently a trainee. With four personnel aboard an airplane, doing relatively low level natural resource surveys, a twin engine is a wise idea. The only available high wing, twin (two) engine aircraft generally available to fly aerial survey are the old Cessna Skymaster (337) and the relatively new Partenavia (68B and Observer). The Aero Commander (500) is not recommended because it must fly too fast, has poor visibility and is not cost effective.

High wing

High wing aircraft offer much better lateral and downward visibility than a low wing aircraft during normal flying. Most all aircraft, with the exception of the Partenavia Observer with its clear plastic nose, causes difficulty in seeing ahead and directly under the aircraft. A low wing aircraft only makes the visibility problem worse.

Performance

Always be familiar with the performance characteristics of the your mission aircraft. Generally, a survey aircraft should not have less than 200 horse power per engine. A Cessna 172 does not have enough horse power to provide any margin of safety during normal survey flying. A Cessna 182 has 235 horse power and is an excellent single engine airplane for one observer under approximately 7,000 feet altitude (depending on temperature). A Cessna 206 is designed to carry heavy payloads and is turbo-charged, making it also an

excellent single engine survey airplane. It performs well at higher altitudes, can carry an extra passenger and equipment, performs well for short take-offs and landings. Pilots only complaints are that it is heavy on the controls and is wider than a 182 making it more difficult to see out the observer's (right) side. A combination of the two is a Cessna 182 RG (retractable gear). It is not turbo-charged, but has a fuel injected type carburator giving greater horsepower at high altitudes, providing that power margin of safety required for safe high mountain flying. With the retractable landing gear, it has a much faster cruising speed making "deadhead" or ferry time more efficient. The Cessna 185 (tail dragger) is also an excellent aerial survey plane that offers slow air speed, excellent maneuverability and short airfield performance. Other high wing, single engine aircraft used include, the DeHavilland Beaver and the Cessna 210.

Flight Patterns

The two most used flight patterns are contour (drainage flying) and grid (parallel flight lines). The type of flight pattern used depends on terrain and survey resources. Flat country is often flown using the grid pattern and mountainous country is usually flown using the contour pattern. Grid pattern is often used when observers and budget dollars are limited since an area can usually be covered in less flight time. Although grid flying covers an area more efficiently, it also has limits in mountainous terrain because the topography can block or shield the observer's view.

Contour flying

Contour flying gets its name from flying survey at approximately the same altitude, while flying up and down drainages, just as contour lines appear on a topography map. This type of flying is actually drainage flying because the observer is constantly following a main drainage and then sub-drainages. Sketch mapping is done with a single observer who has the pilot fly up a drainage with the drainage bottom on the right side (observer's side) of the airplane. This provides the observer the opportunity to follow the creek or river on the ground and on the map to track their location while sketch mapping, and should give the observer a complete ground view from creek to ridge top. When the airplane reaches the head of the drainage, the pilot performs a right turn to let the observer continue to view the ground. Then, the airplane continues back down the drainage, while the observer again views from creek bottom to ridge top on the other side of the drainage that wasn't visible on the route up the drainage. It is important, that at the head (upper limits) of each drainage, the airplane turns right to go back down the drainage only after the observer is confident that all the area will be visible before and after the turn. This clockwise, systematic method gives the observer almost complete coverage of the area to be surveyed.

The topography dictates much to how contour flying is done. It should be noted that this turning to the right method is in reverse to how a pilot would normally fly in a similar situation without conducting a natural resource survey. The pilot normally flies with the ridge on the right giving the pilot an unobstructed view to a safe area to turn the airplane in case of emergency.

Safety concerns include: 1) never fly up drainages directly over the drainage bottom, because, along with reducing the observer's view, it reduces the amount of escape route space available for the pilot to turn the airplane around and back out the drainage, 2) always maintain enough altitude flying up a drainage to allow

for down drafts and power emergencies, and so the airplane engine's power settings aren't pushed to the limits time and time again. It is this aspect of contour flying that requires the observer to have some basic understanding of flight, mountain flying, aircraft performance and pilot concerns. There are many more rules to flying than just staying 500 feet above the ground.

Grid flying

Grid or parallel flight line flying can be an efficient systematic method of covering a planned area. This method can provide complete coverage with the least amount of duplicated coverage. It is generally used in flat or low relief areas with poorly defined terrain. It is often used when two observers are sketchmapping at the same time out opposite sides of the airplane. Depending on the terrain, visibility, insect and disease damage, and experience of the observers, the distance between flight lines should be 4 or 5 miles. Any more space between lines makes the middle area difficult to see and may provide less than complete coverage. Care should be taken to insure that the flight lines are close enough together, so upon completion of the flight map, the flight path is not visible on the map. Inexperienced observers tend to map only what they see close to the airplane, also leaving polygon gaps in the middle between flight lines.

Although grid flying is the most efficient method of flying, limitations include lack of adequate time to see disturbances behind ridges. Crossing high ridges does not provide for low-level viewing of valley bottoms and causes a viewing gap directly under the airplane.

Cardinal directions are usually followed. Direction of flight is optional and may vary depending on time of day and terrain. Flight lines are generally predetermined and marked on the observer's map prior to the flight. Pilots differ in their method to stay on the planned flight line. Compass headings may be followed, section line markings on the ground, such as fence lines, roads and clearcuts are used to "stay on line." Give a refrence point (mountain top, lookout, snow field, ridge notch) far enough ahead to help the pilot visualize the intended path. When following compass headings, it is important to include the declination of the area, since the pilot is flying a magnetic heading (magnetic north) and the observer is following a map heading (true north) on the map. Constant corrections of the flight path can make for less than acceptable conditions for observation and mapping.

Safety concerns include, when flying in mountainous terrain, keeping a high power setting while flying across ridges and maintaining a safe margin of clearance when crossing ridges.

Survey Crew Communications

Flight following

Flight following is included in survey crew communications because the individual conducting the actual flight following on the ground should be considered an integral member of the survey team. Without this individual, the survey can not be conducted. The dispatcher or radio operator should understand the survey mission, the type of flying to be done, know the general area to be surveyed, the type of aircraft, tail number and

passengers on board. This information sharing should be done in person or on the telephone prior to the flight each day.

Regular check-ins by radio should occur every 15 minutes. The primary reason for flight following is for safety, in case of an emergency, such as a forced landing. Keeping this in mind, the check-ins should include a specific landmark that would help a response team determine the search area. Another reason for the check-ins is to help the agency dispatcher manage the unit's airspace. The survey should not continue without some sort of radio comunication with someone on the ground.

The chief observer should know, or have in his/her possession, all radio frequencies that may be needed to maintain radio communication. A complete list of frequencies for the entire survey area is recommended.

Communication equipment

Attemping to fly aerial survey without adequate communication equipment can cause the survey to be inefficient, unsafe, frustrating to all involved and ineffective. Terminating the survey prematurely due to radio problems can be a costly action, both in terms of dollars and time. At a minimum, radio equipment should include a 5-watt programmable radio, an antenna mounted to the outside of the aircraft, noise attenuating aviation headsets with microphone, and an intercom system in the aircraft so all flight members can communicate with each other.

Flight crew

Your survey pilot does much more for you than just fly the airplane. The more you informed the pilot of your mission and intentions, the better team player he or she can be. Without an intercom system in the aircraft, communicating with the pilot was done with a series on hand signals, yelling and body language. Today, most survey airplanes have a built in intercom system. Portable systems are available for use in airplanes without an intercom, but often they are inadequate because they do not usually accommodate radios.

Communicating with your pilot includes, not only telling him or her which direction you want to go, but also what altitude and air speed to fly, where and when to make the turn, what kind of turn to make and where you plan to go next. And when flying a grid survey with an inexperienced pilot, you are usually requesting a slight jog to the left or right to stay on your intended course. The more you talk to survey pilots, the more you will know about the pilot's concerns, flight physics and meteorological conditions affecting the survey. An experienced pilot can also help you plan your mission when you consider such things as airports with fuel, fuel on board (maximum flight time), terrain to be surveyed (do you have the proper aircraft?), and ferry time estimates to help you decide on the most efficient overnight location.

Prior to each flight, all personnel on board the airplane should know the intended plan of the chief observer. Anyone riding in the back seat of a small aircraft should know the approximate length of flight and area to be surveyed. Keeping everyone informed helps reduce surprises for crew members and provides an opportunity for them to be more effective participants.

Navigation

Tracking

Keeping track of the aircraft's exact location is expected of all observers during sketch mapping. One must know his/her location to accurately map forest disturbances. This can present one of the major challenges to new aerial sketch mappers. Each sketch mapper has his/her own method of tracking. Looking ahead, both on the map and on the ground, helps the observer anticipate ground features to be seen. Keeping one's finger moving along the flight path on the map can help track the flight path. Drawing the flight path on the map can help avoid repeating an area. Major land features easily seen from the air, such as lookouts, communication towers, certain mountain peaks and landing fields, should be highlighted on the map prior to the flight to help both the pilot and observer keep track of their location and heading. Loran and GPS technology to determine one's latitude and longitude can be helpful to mark a survey ending point for later return and for the observer who is helplessly lost, but it should not be necessary during routine aerial surveys. Tracking for grid flying is often improved by marking the intended flight path on the map prior to the survey flight. Tracking for contour or drainage flying can be improved by studying the area to be surveyed on the map prior to the survey flight.

Maps

A variety of maps are used to fly initial aerial surveys. Quality of the survey map directly affects the sketch mapper's ability to accurately place polygons and points on the map. Maps good for ground naviation may not be good for aerial navigation. Large-scale maps may be good for detail, but cumbersome in the cockpit due to size. The more political, recreational and transportation information on a map, the lesser the quality of the map for aerial survey purposes. Some common maps used to for sketch mapping include 1:126,720 (1/2 inch equals 1 mile Forest series), 1:100,000 (USDI Geoloical Survey, scale metric topographical), and a variety of other map bases at similar scales. Smaller scale maps, like the USGS 1:250,000 maps, are used in areas where large areas are quickly covered and have few or no other maps available. This occurs in places like Alaska and Canada. A customized map base, primarily for the the use of aerial surveys, has been talked about for decades, but due to the expense and challenges of covering more than National Forest land, little has been attempted. The best maps for aerial survey include; good drainage definition, major land features, such as mountain tops, modern civilization structures easily seen from the air, grass-tree mosaic, water, and major highways. Often, too much detail only detracts from the observer's ability to place the polygon on the map.

Mission Planning

Cost effectiveness

Experience is the best tool for planning an aerial survey mission. An observer who has flown the same area for several years automatically decides where to stay overnight, which area will be flown first, how much area can be flown in one flight, which airfield to go to for fuel and when is it cost effective to stay overnight out of town. A primary consideration when planning an aerial survey is the cost of the airplane per hour versus

the cost of per diem for the crew. When the cost of ferry time back to the home base is greater than per diem costs for the crew, generally it is cost effective to stay out of town. This consideration should be made on a daily and weekly basis. Ferry time to a survey area should be kept to a minimum, since it is aircraft time costs that do not contribute to the actual aerial survey. The ideal survey day requires little to no ferry (or deadhead) time. But since most surveys are done at a Regional level, this isn't possible.

Appropriate airfields

Another important aspect to mission planning is knowing all the appropriate airfields. Most survey days include a mid-day break for lunch and fuel. Again, ferry time for fuel or lunch can be time and dollar consuming. Planning each day to include the best place to go for fuel is good management. If the crew brings a lunch, fuel is the only concern. The observer should include the pilot in mission planning, since the pilot is usually very familiar with fuel needs and ferry times. Different Regions have different policies on which airfields are approved for landings. Many smaller, unpaved airfields require back country certification for pilots. Be familiar with each pilot's agency certification.

Ground transportation

Know before landing at an airfield what type of ground transportation is available. Some forms of ground transportation include commercial rental cars, agency loaner vehicles, taxis, motel shuttles or agency personnel to provide a ride from the airport. It is best to make arrangements before your arrival since the summer months are busy and rental cars may be unavailable without reservations.

Communication considerations

Always carry with you a list of all available radio frequencies that you may possibly need. It is a good idea to have a list of not only the agency flight following radio frequencies, but also other agency local frequencies, including other federal, state and law enforcement agencies. Always carry a list of phone numbers of all people you may need to contact. It is not uncommon to lose radio contact, be forced to land and call the dispatcher flight following you. A 5-watt portable, hand-held programmable radio is recommended as a back up.

Final Safety Comments

Make sure you have the appropriate aircraft for the planned mission. An underpowered airplane in the mountains is a major safety consern. Understand density altitude and how it effects your airplane. Fly low only when flying in a direction that has an escape route, like down a drainage. Never fly below 500 feet above ground level. Be aware of and understand wind turbulence in mountain flying.

Protect your hearing. Hearing loss is common with long time aerial observers. Don't let it happen to you. Always where noise attenuating headsets that seal well and are rated for approximately 24 decibels. If headsets are not available be sure to use ear plugs.

Sunglasses are an important safety item as well as a color enhancement tool. Sunglasses, first protect your eyes from bright sunlight and help reduce eye and body fatigue. A good amber to red tint can provide the observer greater contrast between green live trees and red dead trees or foliage. Sunglasses should not be so dark as to hamper the observer's ability to read the map in the cockpit of the airplane.

Weather plays a large part in the daily aerial survey operations. Weather can be and is usually the cause of changes in plans. Being flexible to complete aerial surveys is a known aspect of the job. One way to help yourself be flexible, is to always carry enough additional personal items on the plane to keep yourself comfortable when you find yourself forced to spend the night in some unscheduled town, airfield or pasture. Survival is more than just an extra tooth brush.

Never fly an aerial survey mission without proper training. Low level, aerial reconnaissance flying requires serious attention to details and should never be taken lightly. Yet, it is an excellent, cost effective method to observe forest disturbances. If all aviation safety considerations are followed, a safe aerial survey mission can be accomplished. The best way to learn how to conduct safe and effective aerial surveys is to be trained on the job by a senior observer, who has several years experience. This mentor program has been used for the past forty years, since no formal training has ever been offered.

Acknowledgements

Thanks to the mentoring of senior observer Tommy F. Gregg, during the late 1970's in the Pacific Northwest Region, I was able to understand the importance of the aerial survey mission, its daily challenges to the observer and catch his infectious enthusiasm to capture on a map what can be seen from the air. Tommy says, "Fly low and slow and don't miss anything".

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PEST/HOST INTERACTIONS AND FPM/A&FM INTERACTIONS

David R. Bridgwater

Forest Insects and Diseases, Natural Resources,
USDA Forest Service, Portland, Oregon 97208

Pest/Host Interactions

During an aerial insect detection survey, we normally, in a broad sense, find trees effected by insects, diseases, animals and abiotic factors. Trees effected by insects can generally be subdivided into bark beetles and defoliators. However, defoliation can be caused by not only our typical defoliators such as spruce budworm or tussock moth, but also by sucking insects that result in defoliation or mortality.

It is my opinion that bark beetles preferentially attack trees that are in a weakened condition. The cause of this weakened condition can be many factors or a combination of factors. Stand over stocking, drought, root disease, lightning, defoliation, soil compaction, and mechanical damage are some of the factors that can make a tree susceptible to bark beetle attack. When bark beetles successfully attack a tree, most produce a population aggregating pheromone. This chemical, or mix of chemicals, draws other bark beetles to the tree. When the number of attacks on a tree is high enough, a switching occurs, and the beetles start attacking adjacent trees, in some cases overwhelming a normally resistant tree. This action is what produces beetle spots of mortality that can involve a few trees or cover much larger areas. As the beetles enter the tree, many of them passively carry a fungi that infects the trees and blocks off the trees' conductive tissue. This, combined with the girdling effect of the beetles and/or their larvae feeding in the cambium, results in rapid tree death. This usually causes the crown to fade within 1 year. Other organisms such as root disease often kill a tree more slowly.

The classical defoliators consume the foliage, imparting an off-color to the trees or change in texture of the canopy caused by the lack of foliage. The foliage consumed can be just the new foliage, just the old foliage or both. This feeding reduces the photosynthetic ability of the tree and can result in growth loss, top-kill and mortality depending on the level of defoliation and its duration. Defoliated trees are also much more susceptible to other organisms such as bark beetles. Dry weather patterns may help defoliators by providing a more favorable climate for their larvae to grow, and some have speculated that periods of drought result in a change in the chemical composition of the leaves thereby making the leaves a better food source.

The sucking insects also cause a type of defoliation. In some cases, better growing trees are preferred as hosts. These insects suck the plant juices out of the trees. This results in an over-all weakening of the tree either by loss of plant juices, leaves being damaged to the point they stop photosynthesis and fall from the tree, or the tree's response to the feeding injury. And, can result in total defoliation, growth loss, or mortality.

Animal damage is usually the result of animals stripping the bark from trees and feeding on the cambium layer. While this can result in the tree being infested by other organisms, death is usually rapid and caused by the girdling of the tree as a result of feeding.

FPM/A&FM Interactions

The aviation programs in our land management agencies were developed primarily in response to the ever increasing use of aircraft to combat fires. As a result, most of the policies and regulations were developed to meet concerns raised by this type of activity. Other aircraft uses were either not considered or were given much less priority because of the perceived minor use of aircraft for other activities.

We, the other users of aircraft, have been fighting an up-hill battle to gain recognition as other significant aerial programs. In the Pacific Northwest Region, we have made tremendous strides. We have a person designated as a Forest Pest Management Aviation Officer. This person operates in the same manner as a Forest Aviation Officer. Some of the improvement in the relationships include:

the Regional Aviation Staff operates more closely with us and our State cooperators than in the past,

the Forest Aviation Officer is more aware of our activity,

field dispatchers better understand our flight mission and why we are there,

a better tie-in with airspace coordination,

increased safety awareness on our part,

increased input into our contracting by the Aviation Group to help us obtain the aircraft best suited to our mission,

improved networking with the Forest Service aviation community which increased our knowledge of other activities and news items which may pertain to our missions.

All of this helps to have a more efficient, effective and safe aerial survey.

SOUTHWEST REGION FOREST PEST MANAGEMENT GIS SUMMARY

Michelle Frank

Forest Pest Management, Arizona Zone Office, Southwest Region,
USDA Forest Service, Southwest Forest Sciences Complex,
Flagstaff, Arizona 86001

At this time, May 1994, the Southwest Region (R-3) GIS capability resides in the Arizona Zone only and the New Mexico Zone hopes to have GIS in the near future.

Personnel and Responsibilities:

1 GS-404-09; Program Manager/Data capture/Analysis/Products
1 GS-404-04 or -05 (03 months/year); Data capture/Analysis/Products

Hardware and Software:

- Most data is digitized using a backlit Summagraphics Microgrid II digitizer.
- LTPlus is run on a generic 386 personal computer with 2 hard drives, and a Bernouilli drive.
- An HP Draftmaster RX Plus plotter is used for creating map products.
- LTPlus version 2.36 is used for digitizing pest polygons.
- Arc/Info is used for analysis. We are cooperating with the Arizona State Land Department to produce the maps and conduct the analysis on their system using Arc/Info. This effort provides the State with the Federal lands pest information and FPM is able to analyze and share data with the State.

Current GIS Projects:

- Annual aerial detection survey - current year's as well as backlog.
  Current goal is to automate data back to 1974. This covers the Arizona Zone area only.
- We have discussed automating our permanent plot locations.
- The Arizona Zone is working in cooperation with the Rocky Mountain Station to automate watershed data for a project in Tapalpa, Mexico. This will include digitizing and scanning information from maps/surveys, as well as assistance with videography.

Spatial Data Layers available:

- Annual aerial detection survey data for 1988-1993.

Discussion:

Approximately 99 percent of R-3 FPM (Arizona Zone) GIS time is used for aerial detection survey data. We provide hard copy maps as well as electronic data to be used in forest planning, etc.

Over the last 18 months FPM has been working with the Regional office GIS data standards group to develop regional standards and provide review. R-3 FPM has GIS data standards in place.

INTERMOUNTAIN REGION FOREST PEST MANAGEMENT GIS OPERATION

Richard L. Halsey

Forest Pest Management, Boise Field Office, Intermountain Region,
USDA Forest Service, Boise, Idaho 84403

Personnel

Boise Field Office:

Joy Roberts - Computer Analyst/Programmer

GIS coordinator: oversees hardware/software configuration/maintenance/replacement for all State & Private Forestry and FPM computers in Region 4; performs analysis and prepares maps on a project level.

Dick Halsey - Biological Technician

GIS system manager; maintains hardware/software for GIS computers at the Boise Field Office; oversees all aerial detection survey GIS related activities; prepares maps and performs some analysis on a project level.

Ogden Field Office:

Dawn Hansen - Entomologist

Prepares maps and performs some analysis on a project level.

Valerie DeBlander - Forestry Technician

Prepares maps and performs some analysis on a project level.

Hardware/Software:

Boise Field Office

Data General Aviion 410 workstation w/32mg ram	Used for digitizing
DG UNIX 5.4R-3.00	primary data storage
Arc/Info 6.2	special projects
PC 386/33 w/4mg ram	Used for editing and plotting
MS DOS 5.0, Windows 3.1	secondary data storage
PC-Arc/Info 3.41	special projects
PC-Arcview 1.0	documentation
Calcomp 9100 digitizer	All peripherals can be
HP 7595A Draftmaster I 8 pen plotter	operated by either computer
HP Laserjet III printer	
Epson EX1000 dot matrix printer	
Airborne Video Camera system	Being evaluated

Ogden Field Office

Currently uses Regional Office equipment for GIS related activities.

GIS Activities within FPM:

Aerial Detection Survey(ADS):

FPM prepares about 350 maps with current ADS information for annual distribution. In addition we prepare about 100 additional maps tailored to specific user requests, and distribute digital data to 6 forests and a number of private and state organizations. We tabulate and summarize all ADS information for Regional and National reports. We also have over 30 years of hard copy ADS maps that are gradually being converted to digital format and made available for distribution and analysis.

Special Projects:

Projects that FPM has been, or is currently involved with include preparing trap location maps for a cooperative gypsy moth program with Russia, and preparing maps to summarize and display data for the gypsy moth program in Utah; providing ADS and GIS training to two individuals from the Peoples' Republic of China in a United Nations cooperative agreement; evaluating GPS and airborne video technology to see how they might fit in to our survey program and GIS; preparing maps for biological evaluations and reports; and to make pest overlay maps to show insect trends.

Metadata:

FPM participates as a member of the Idaho Geographic Information Advisory Committee-metadata subcommittee developing metadata standards for GIS users in Idaho and is currently updating existing ADS digital coverage's to meet these standards.

GIS Activities outside of FPM:

Virtually all forests in Region 4 have some type of GIS equipment and are using it for a variety of activities some of which are insect and disease related. The Caribou NF has hazard rated some of their timber stands using GIS with information provided by FPM. Forests which have some digital ADS information include the Boise NF, who is using the data and evaluating the need for revising their forest plan; the Payette NF, who will use the information to hazard rate some of their timber stands; the Wasatch-Cache NF, Manti-La Sal NF, and Dixie NF, who have digital data but are not known to be actively using it at the present time; and the Targhee NF who is just beginning to receive digital ADS information.

Insect & Disease standards:

Insect and disease standards follow this, used with stand inventory in Region 4. Insect and disease codes used by ADS have finer divisions and have been used by FPM since the early eighties with few modifications.

Boise Field Office
1750 Front St., Rm 202
Boise, Idaho 83702
(208) 364-4220
DG (R04F02A)

Ogden Field Office
4746 S. 1900 E.
Ogden, Utah 84403
(801) 476-9720
DG: (S22L02A)

PACIFIC SOUTHWEST REGION FOREST PEST MANAGEMENT GIS SUMMARY

Sheri L. Smith

Forest Pest Management, Lassen National Forest,
USDA Forest Service, Susanville, California 96130

Personnel and Responsibilities:

The Pacific Southwest Region (R-5) FPM has no personnel dedicated to GIS. Efforts are underway to obtain a half-time position to be shared with the remote sensing lab in Sacramento.

Hardware and Software:

Data Capture for aerial surveys is conducted at the Forest level
- Most data is digitized or scanned
- LTPlus is run on a PC

Data Manipulation and product generation
- DWRIS - run on DG.
- MOSS - run on DG.

Current GIS Projects:

Annual aerial detection survey
- 1992 - 1 National Forest
- 1993 - 4 National Forests
- 1994 - 10 National Forests

Current contract with Pacific Meridian Resources to produce GIS maps for the following insects and pathogens. Maps will be in MOSS, ARC/INFO and hard copy.

Detection maps
- Black stain root disease
- Eucalyptus long-horned borer
- Pitch canker
- Gypsy moth
- Dutch elm disease
- Port Orford cedar root disease
- White pine blister rust

Historical defoliator outbreak areas

- Pandora moth
- Douglas-fir tussock moth
- Lodgepole needleminer
- Modoc budworm

Plot location maps

- Ozone monitoring stations
- Ozone damage trend plots

Spatial Data Layers available:

Annual aerial detection survey - 1991-1993.
All above mentioned maps when contract is completed.
Port orford cedar and *Phytophora lateralis* occurrences in R-5 and R-6.

Discussion:

R-5 I&D standards are in place for the aerial surveys. Other standards are being developed under the GIS contract.

PACIFIC NORTHWEST REGION FOREST INSECTS AND DISEASES GIS SUMMARY

Julie L. Johnson

Forest Insects and Diseases, Natural Resources,
USDA Forest Service, Portland, Oregon 97208

Personnel and Responsibilities:

1 GS-460-11; GIS Coordinator/Program Manager/Analysis/Products
1 GS-404-07 (10 months/year); Data capture/Analysis/Products

Hardware and Software:

Data Capture

Most data is scanned using a borrowed scanner and LDScan software.
LTPlus is run on a Gateway 2000 486/33.
Altek digitizer.

Data Manipulation and product generation

Arc/Info 6.1.2-run on an IBM X-terminal LAN'ed to an IBM workstation.
MOSS - run on the DG.
R-6MAP - run on the DG.
Plots generated in both Arc/Info and MOSS. Plots generated in Arc/Info are plotted on an electrostatic plotter; plots generated in MOSS and R-6MAP are plotted on an HP draftmaster.

Current GIS Data Automation and Analysis Projects:

Annual aerial detection survey - current year's as well as backlog.

Current goal is to automate data back to 1970 (hard copy map data is available all the way back to 1947 for R-6) - regional coverage.

Dwarf mistletoe plot locations - forest coverage
Root disease surveys - forest coverage.
Change detection using satellite imagery and testing the Most Similar

Neighbor method to determine causal agent(s) for damage identified with the change detection process. This is a proposed project for FY 95 - district coverage.

Douglas-fir Tussock Moth trap locations - regional coverage.
Western Spruce Budworm spray effectiveness analysis - using aerial survey data and spray project boundaries - regional analysis.

Spatial Data Layers available:

Annual aerial detection survey data for 1980-1993.
Spruce Budworm spray project analysis areas for 1980-1992.
Port orford cedar and *Phytophora lateralis* occurrences in R-5 and R-6.

Discussion:

Approximately 65 percent of R-6 FID GIS use is focused on the automation, manipulation and transfer of the annual aerial detection survey data. This is our most complete and extensive data set and it is used by many agencies throughout the Region.

The other 35 percent of our time is spent on the more project-oriented uses listed above.

R-6 I&D standards have been in place for 4 years, but they are still only Regional standards. We are hoping to incorporate and/or move to national standards when they are in place.

SOUTHERN REGION FOREST HEALTH ANALYSIS TEAM AND GIS DATABASE INFORMATION

Theresa Valentine *

Forest Health Analysis Team, Southern Region,
USDA Forest Service, Atlanta, Georgia 30367

Personnel and Responsibilities:

Regional Office:	*R08A*	*404-347-2961*
Dan Brown		Pathology Group Leader
Theresa Valentine		Forest Health Analytical Biologist GS12
Chris Kahle		Cartographic Technician GS7 3/4 time
Michelle Morrison		Cartographic Technician GS5 1/2 time
Vacant position		Forest Health Analytical Biologist GS11
Ashville Field Office:	*S29A*	*704-257-4843*
Brian Spears (50 percent)		Forest Health Analytical Biologist GS12
Don Tweed		GIS Specialist
Steve Covington		Biological Technician
Alexandria Field Office:	*R08F06A*	*318-473-7286*
Doug Rubel		Forest Health Analytical Biologist GS9

Hardware and Software:

Regional office:

Data General MV15000 mini computer running ARC/INFO version 5.0. Calcomp electrostatic plotter, two PC's capable of running PC ARC/INFO, digitizer, and numerous graphics terminals.

Field offices:

Both field offices have PCs to run the GypsES program (gypsy moth expert system). This system uses GRASS. Both field offices have Sun workstations and ARC/INFO version 6.1.

Both field offices have been using the MIPS system with aerial videography projects.

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* Theresa Valentine has since become the GIS Adminstrator for the Oregon State Service Center for Geographic Information Systems, Salem, Oregon 97310.

Current GIS Projects:

Publications:

FHAT is working on three publications scheduled for release this fiscal year. Topics are data preparation, FHAT awareness, and Forest Health in the South.

Gypsy Moth:

Suppression projects are happening in Arkansas, Virginia, North Carolina, and Tennessee. GIS has been used for the preparation of contract specifications, EA preparation, public meetings, and project planning.

FHAT is analyzing data for the National Gypsy moth EIS. We are analyzing spray blocks over several years in Virginia.

Southern Pine Beetle:

The Southern Pine Beetle Demonstration project is wrapping up and FHAT will be providing analysis for the final report. Twelve products have been defined ranging from risk assessment to animation of spots over time.

Forest Health Monitoring.

Documentation of the atlas layers is underway for inclusion in the Forest Health publication (data covers the R8). Enclosed is a list of data available for the Southern Region.

Ashville field office is working on Slow the Spread Gypsy Moth, Gypsy Moth suppression, Southern Pine Beetle, Gypsy Moth eradication projects in Tennessee and North Carolina, and other minor projects.

The Alexandria field office is working with the INFORMS-Region8 expert system, SPBIX (Southern Pine Beetle expert system), and IPM Decision Key. They also work with MIPS and ADRISI for the integration of aerial videography and GIS.

Discussion:

Emphasis on project work has shifted from the Regional Office to the field units. RO role will be to coordinate activities in the field and maintain the Forest Health Atlas. RO is working on some projects until field offices are fully operational and to finish projects like the Southern Pine Beetle Demonstration Project report.

FHAT is scheduled to be a pilot unit for project 615. At that time, hardware and software will be updated.

We expect the role of FHAT in Forest Health Monitoring to increase over the next year. As we acquire project 615 equipment, we will move toward helping others have access to forest health data (states, other federal, counties, private cooperators).

Information in the Southern Region Forest Health GIS Database

Gypsy Moth

Defoliation in VA, WV	1984 - 1993
Mortality in VA	1992
Spray blocks in VA, WV, AR, GA	1986 - 1993
Male moth trap catch	1988 - 1993 (for specific eradication projects)
Egg mass surveys	(for specific eradication projects)
Fall cankerworm defoliation	select years in VA

Southern Pine Beetle (SPB) Demonstration Area Project

SPB spots	1988 - 1993 (Oconee & Homochitto NFs)
SPB hazard rating	1988, 1989, and comparison by stand

Red-cockaded woodpecker colony sites and habitat areas in select NFs

Spruce-Fir

Mortality	Transportation	Ownership
Disturbance history	Drainages	
Study plot locations	Elevation	

Forest Health Atlas

Forests

Forest distribution in the Southeast by county; 22 forest types in cubic feet/acre

SAF forest types in the US

Pests & Diseases

County occurrence data for:

Dogwood anthracnose	1986 - 1993
SPB	1960 - 1993
Littleleaf disease	historical occurrence, 1951 survey
Fusiform rust	1977 and 1987 surveys
Butternut canker	occurrence

Hemlock woolly adelgid

Oak decline plot data for the Southeast (points)

Root rot hazard, attached to corresponding soils

Littleleaf disease, attached to corresponding soils

Soils

State soil association maps; need to acquire STATSGO data from Soil Conservation Service.

Ozone

Seven hour average by month	April - October 1978 - 1990 Kriged data for the Southeast

Weather

Data from 1951 - 1984, being updated to 1990. Includes all of the Southeast except western OK and TX and northern KY and VA.

Acquire *National Forest* data from the National Forests.

NORTHEASTERN AREA FOREST HEALTH PROTECTION GIS SUMMARY

Susan J. DeLost

Forest Health Protection, Northeastern Area,
USDA Forest Service, Morgantown, West Virginia 26505

Personnel and Responsibilities:

The GIS responsibilities for Forest Health Protection (known as Forest Pest Management in other areas of the country) in the Northeastern Area (NA) are shared among the three field offices:

1. Morgantown, WV (MFO)	1 Cartographer (GS-1370-11) NA FHP GIS Coordinator
	1 Computer Assistant (GS-335-07) (25 percent GIS)
2. St. Paul, MN (SPFO)	1 Computer Assistant (GS-335-08)
3. Durham, NH (DFO)	1 Forester (GS-460-11)
	1 Biologist (GS-401-09)

We all have responsibilities for data capture, analysis, and product generation. The Northeastern Area is comprised of 20 states and the District of Columbia. Each field office has an area of responsibility that covers several states near the field office. The Durham office's area covers Maine, New Hampshire, Vermont, Connecticut, Rhode Island, Massachusetts, and New York. Morgantown's area covers New Jersey, Delaware, Maryland, Pennsylvania, West Virginia, and Ohio; and St. Paul's area covers Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, and Missouri. Within each area of responsibility, field office employees interact with the state cooperators; National Forest personnel and counterparts at other federal sites in providing support for pest identification and suppression programs and more recently with forest health programs.

Hardware and Software:

Data Capture

Gypsy moth and other pest data is digitized using ARC/INFO or pcARC/INFO; some data is obtained in digital format from our state cooperators; base information is obtained from USGS DLG files or other sources. Each site has a large format Calcomp digitizing board.

Data Manipulation and product generation

Each site runs ARC/INFO on:

a. Morgantown, WV: Hewlett-Packard series 9000 model 705 workstation with 64MB RAM and 3.0GB of storage; 4mm DAT cartridge; CD-ROM; 1/4" QIC tape drive. Output devices: Calcomp Colorview Thermal Wax 300 dpi plotter (11" by 17") and Calcomp Model 1023 8-pen plotter (24" by 36").

b. St. Paul, MN: Hewlett-Packard workstation as above, minus the QIC drive. Output devices: Calcomp Postscript Thermal Wax plotter (8-1/2" by 11") and Calcomp model 1023 8-pen plotter (24" by 30").

c. Durham, NH: SUN Sparc 2 workstation with 64MB system memory and 2.0GB of storage; CD-ROM; 1/4" QIC tape drive. Output devices: Calcomp model 1043 8-pen plotter and Hewlett-Packard DesignJet 650C plotter.

Current GIS Projects:

Produce maps for the Northeastern Area Forest Health Report (1991, 1992, 1993 - in work) in support of the Forest Health Monitoring Program

Incorporate incidence data by county into GIS for larger pine shoot beetle, hemlock looper, hemlock wooly adelgid, spruce budworm, gypsy moth, ash yellows, beech bark disease, butternut canker, forest tent caterpillar, and dogwood anthracnose

Goal is to collect and incorporate damage data in areas surveyed where damage is greater than 5,000 acres (will be recorded as polygonal data). Data to be recorded on 1:100,000 scale or larger maps:

- acquire base information for other federal sites,
- incorporate gypsy moth and hemlock looper defoliation data from aerial surveys into GIS,
- assist state cooperators in implementing GIS in pest management and forest health programs,
- provide GIS support for pest suppression activities on Native American lands,
- evaluating usefulness of MIPS (Map and Image Processing System) software to process aerial videography,
- acquire other relevant data such as: soils, weather, and forest cover type (AVHRR data),
- continue to support North American Maple Project (NAMP) - DFO,
- digitize Ecomap Section and Sub-section delineations as defined by a working group comprised of Forest Resource Management and Research units and outside cooperators.

Spatial Data Layers available:

Major Forest Cover Types of the conterminous U.S. - from Eyre, 1980. Society of American Foresters. Digitized version produced in 1989 by S.H. Azevedo, Forest Ozone Team, USEPA Environmental Research Lab, Corvallis, Oregon. Scale of source: 1:7,500,000.

Forest pest data on a county-level basis for 20 Northeastern Area states for 1991, 1992, and 1993 (in-work).

Native tree species range information within the NA for:

- Eastern Hemlock
- Spruce-Fir
- American Chestnut
- Sugar Maple
- American Beech
- Butternut
- Flowering Dogwood

Tree species range map information was digitized from Silvics of North America, Volumes 1 and 2 (Burns 1990).

Data for National Forests at 1:100,000 scale in the SPFO area (includes: roads, water, boundaries, sections, gypsy moth trap data, forest type).

State and county boundaries at 1:2,000,000 scale from USGS DLG data (does not include Alaska or Hawaii).

Discussion:

The NA FHP GIS Team meets several times each year to discuss GIS projects of common concern (e.g., the NA Forest Health Report); data standards; and implementation issues.

In October 1993, the NA FHP GIS Team met with the Region 9 GIS Coordinating Committee for the first time. We met to identify common needs and areas of common interest. This was necessary because, unlike other areas of the country, there has not been a strong link between the National Forests and State and Private Forestry. The Northeastern Area and Region 9, which encompass roughly the same area, function independently of each other in most cases. In the area of GIS implementation, we felt a need to communicate and coordinate in a proactive manner.

Some data collection and reporting standards are being developed by the Forest Health Team. We plan to move to national standards when they are developed.

UPDATE ON CURRENT GIS APPLICATIONS IN THE METHODS APPLICATION GROUP

David J. Roschke

Methods Application Group, Forest Pest Management,
USDA Forest Service, Ft. Collins, Colorado 80524

The Methods Application Group (MAG) has been working on a variety of GIS-related projects, including the following:

Computer-Aided Classification of Forest Stand Cover Types from Airborne Video Imagery

MAG flew an airborne video mission for the Nez Perce National Forest in 1992 to acquire true-color imagery at a 1-mile swath width for use in exploring issues such as range allotment and analysis, noxious weeds, pest defoliation, and land ownership in riparian areas. Forest staff were interested in assessing the usefulness of video imagery in computer-aided classification of forest stand cover types.

An area was selected for which a stand map was available and stand data had been collected. The stand map was digitized into Arc/Info. For this test, stands were lumped into four general categories. Video frames to cover the area were selected and captured with MIPS software. The frames were then georeferenced to a scanned orthophoto quad, warped, and mosaicked using Erdas software to produce a single, rectified, digital image for the entire area.

Erdas was also used for the analysis and classification process. Color signatures for each of the stand classifications were extracted from the video imagery based on the stand map. Each color signature was analyzed to determine whether the spectral distributions between the known images were different enough to allow classification, and which band combinations would yield the best results.

Each pixel was examined independently, compared to class signatures, and assigned to a class. Four different algorithms for classification were tested and the results evaluated.

The result was that there was little or no relationship between the classifications assigned to pixels and the class (stand) boundaries regardless of the algorithm used. The project team concluded that true color video imagery flown at a 1-mile swath width lacked sufficient spectral information to discern differences among the four cover types studied. This held true both over the entire area (five adjacent flight lines), and within single flight lines.

The methods and results are documented in a MAG in-house report, "Computer-Aided Classification of Forest Stand Cover Types from Airborne Video Imagery," by Jeanine LaFontaine Paschke and Lowell G. Lewis, dated March 22, 1994.

Use of an Airborne Video Camera System for Detecting and Mapping Gypsy Moth Defoliation

Three methods for the detection of gypsy moth defoliation were compared to evaluate their relative costs and accuracy. The study area under consideration was on the George Washington National Forest in Virginia. The three methods of detection were (1) aerial sketch mapping, (2) true color super VHS airborne video imagery at a 1¼-mile swath width, and (3) color infrared aerial photography.

The video imagery was interpreted for defoliation in three ways: (2A) The video tape was viewed in the office to allow sketch mapping to a 7.5 minute topographic map from a tape monitor. (2B) The second method was the same as the first except the defoliation was sketchmapped to an orthophotoquad rather than to a map. (2C) Video frames to provide full coverage of the area were selected, captured, georeferenced to a scanned orthophotoquad, warped, and mosaicked with MIPS software to produce a single rectified digital image for the entire area. This image was used in the office for on-screen digitizing.

The color infrared photographs were photo-interpreted for defoliation, and the results transferred to a 7.5 minute topographic map with a Zoom Transfer Scope. These results were used as the control against which the other methods were compared for accuracy. Arc/Info was used to digitize, analyze, and compare the results of the three methods relative to the control.

The best spatial accuracy was obtained with on-screen digitization (2C), followed by office sketch mapping to orthophotoquad (2B), followed by office sketch mapping to topo map (2A). Aerial sketch mapping was least accurate. With respect only to person-hours expended and photo processing costs, the costs of aerial sketch mapping and the two forms of office sketch mapping from video tape were relatively closely clustered, followed by color infrared photo-interpretation, followed by on-screen digitization. When the prorated costs of camera systems, computer hardware, and software were also considered, the methods ranked in the same order, but there was a greater difference in cost between aerial sketch mapping and the two forms of office sketch mapping.

The methods and results are documented in an as-yet unpublished paper entitled "Use of an Airborne Video Camera System for Detecting and Mapping Gypsy Moth Defoliation," by Brian M. Spears, Lowell Lewis, John R. Omer, Richard J. Myhre, and Robert E. Acciavatti. This paper is currently in draft form.

Spatial Rulebases on the Jessieville Ranger District

INFORMS-R8 (the Integrated Forest Resource Management System developed for use in Region 8) is an integrated decision support system that has been developed as part of a cooperative effort involving R8 Forest Pest Management, the National Forests in Texas, Texas A&M University, and Washington Office Forest Pest Management. INFORMS-R8 has recently been installed at a new pilot site--the Jessieville Ranger District on the Ouachita National Forest in Arkansas.

The Jessieville RD recently held a knowledge engineering session to identify knowledge about local conditions and the implementation of the forest plan for incorporation into rulebases. Rulebases have been in use on the Neches RD on the Davy Crockett National Forest in Texas for a few years in conjunction with

INFORMS-R8, but the Jessieville RD has added a new twist--some of the rulebases require spatial analysis that can be accomplished only through GIS.

The following are some examples of how spatial analysis can be used within rulebases for different purposes. (1) The need for road closures can be identified through examination of road densities on a compartment basis. (2) Foraging areas for a management indicator species (scarlet tanager) can be identified as contiguous areas that meet certain spatial requirements and share certain attributes. (3) Potential scenic viewpoints can be identified as points on trails and roads on slopes that meet certain criteria for length and steepness. (4) The survey intensity needed to identify potential cultural sites over large project areas can be assigned on a local level by proximity to water, slope, aspect, and other land features.

The rulebases are uncompiled text files containing rules that represent knowledge about analyzing or evaluating situations. They are interpreted and processed by software called CLIPS (C Language Integrated Production System), a public domain expert system developed by NASA. CLIPS has been modified by the STARR (Systems Technology And Renewable Resource) Lab at Texas A&M University, and incorporated into INFORMS-R8. The modifications added functions that can be called from within the rulebases to access data stored in the Oracle relational database management system, and can run and access the results from Arc/Info AMLs.

For example, in searching for potential foraging areas for the scarlet tanager, the rulebase uses AMLs to locate areas that meet certain basal area and age requirements, occupy at least 250 contiguous acres, and are always at least ⅛-mile wide. The potential foraging areas are stored in a new coverage, which can later be displayed and used through INFORMS-R8. The Arc/Info DB Integrator is used to build an Oracle table that contains information that will be used by the rulebase to rate the forage potential of the areas meeting the spatial criteria.

For more information, contact Ron Perisho on the Jessieville RD or Steve Williams at MAG.

Technical Development Project for Forest Health and Ecosystem Management Planning

Region 1 FPM and MAG are involved in a new technical development project, entitled "Develop Methods for Assessing Forest Health for Ecosystem Management Planning." The purpose of the TDP is to develop methods to assess the role of insects and pathogens in forest succession, and describe how forests are likely to change as a result or in the absence of management activities. The results will be used to complete a Forest Health Assessment for the project area. The methods will be documented for use in further assessments in Region 1, and should be applicable in other Regions as well.

The first phase of the project will involve developing GIS and relational database representations of two sets of data available for the entire project area -- one from the 1930's and one from 1975. The two data sets will provide an opportunity for both spatial and temporal analysis of the effects of insects and pathogens in conjunction with vegetative characteristics on ecological succession.

The second phase of the project will build on the results of the first to answer the question, "What are the most likely pathways and timeframes for natural and human influenced changes in the landscape?"

The third phase of the project will be the production of a Forest Health Assessment through the use of the Forest Vegetation Simulator to predict landscape conditions for the next 100 years.

For more information contact Sue Hagle in the Northern Region Office in Missoula, Montana, or Steve Williams or Ross Pywell at MAG.

AIRBORNE VIDEO
WESTERN PERSPECTIVES

Steve Dudley

Forest Pest Management, Arizona Zone Office, Southwest Region,
USDA Forest Service, Southwest Forest Sciences Complex,
Flagstaff, Arizona 86001

Airborne videography is rapidly becoming popular in the western United States because of its ability to supply data in short time frames. Many natural areas of the western US are isolated enough that the feasibility of continually conducting or monitoring on plot surveys is difficult. Non traditional methods of data acquisition, such as airborne videography, offer timeliness, affordability, and accuracy that land managers can incorporate into GIS (Lachowski et al. 1992).

The new found popularity airborne videography is experiencing in the west in all disciplines can, to an extent, be contributed to the pioneering efforts in the field by the Methods Application Group (MAG) in Fort Collins. The consolidated procurement package features a simple but complete operational system for the Forest Service and other natural resource agencies wishing a tested and standardized system. Since the USDA Forest Service, Forest Pest Management (FPM) group was a co-sponsor in the development of airborne videography, many of the western regional FPM offices were the first to acquire operational systems. Airborne video image acquisition began to validate the expectations for which it was developed.

1. It is relatively inexpensive to acquire imagery.

2. Imagery can be acquired quickly.

    A. Because no film development is needed, quick turn-around time is possible.

    B. A mission can be planned and executed at a moment's notice to meet unpredictable temporal events.

3. Inexperienced personnel can be readily trained in airborne video image acquisition.

4. Production of high-quality imagery for incorporation with GIS and "heads up" sketch mapping (Myhre 1992).

However, along with the expected benefits we've discovered that environmental factors existing in the west can offer the videographer some interesting challenges. Geographically, the west is typified by low, sweeping desert panoramas and eroded mesas to the forested peaks of the Rocky Mountains and the sky islands of the southwest. Landscape phenomenon, combined with weather, can provide some of the most challenging filming situations. Some of the common problems that create difficult filming conditions for small aircraft include orographic lifting, created when layers of air flow in response to pressure gradients are lifted up over mountains.

Convection encountered when low-lying desert floors heat during the daytime making surface air unstable and force air upwards. And convection summertime currents coupled with the importation in the upper atmosphere of moist air leading to sudden and rapid development of intense squalls and thunderstorms. These conditions cause buffetting which can lead to blurred or jittery imagery. Chronic atmospheric disturbances, such as these, generally cause the discontinuation of filming. Beginning the filming early in the morning before convection flows begin, or moving to the evening when convection flows subside are sometimes viable alternatives if it is the right time of the year. Generally, during fall to spring months filming opportunity windows are short because the sun's zenith is short lived. Most of the morning and evening hours are not useful as long, deep shadows are cast by trees, canyons, and any other relief on the landscape.

Due to the degree of variability in geophysical features, it is not uncommon to have a subject site that has wide elevation fluctuations. Subject matter can be spread over peaks 10,000 feet in elevation and into canyons as low as 4,000 feet elevation. Calculating the height above sea level (MSL) with focal lengths of lenses in mind almost precludes the use of one of the telephoto selections in conjunction with flying at altitudes requiring oxygen. Otherwise, the continually changing landscape beneath the plane fluctuates so wildly it is almost impossible to keep swath width (ground coverage) constant. Results are blurred imagery, gaps in coverage on sidelaps, difficulty in registering digital imagery to adjoining frames, and safety concerns for pilot and crew. Of course, flying at these altitudes any time of the year, and particularly in fall to spring months, it can become quite cold. Light aircraft heaters for the rear-most passengers are not noted for their efficiency. In order to address the possibility of having to film at upper altitudes, the Cessna 206 and 206 turbo, Cessna 207, Cessna 210, Queen air, and Partenavia Observer tend to be favored as videography aircraft.

With all the potential problems to overcome, the videographer must take special care in planning a mission taking into consideration the objectives of the mission, time of year, type of aircraft, weather, pilot experience with mapping missions, and terrain. Planning should begin well ahead of the flight and should include maps identifying the subject area, flight lines plotted to reflect swath widths, flight altitudes, and directions. The mission and its objectives should be thoroughly reviewed with the pilot and maps made available for the crew. Flight following should be arranged in advance. Preflight equipment adjustments and checks should be performed. Special equipment for a particular mission should be secured (i.e., navigation camera and monitor for low-altitude flying of narrow swath widths, or oxygen tanks topped off in aircraft for a high-altitude flight). When all is ready and the pilot and crew thoroughly understand what is expected of them, still plan in extra time to allow for unexpected delays caused by weather.

Even with all the special precautions and planning, airborne videography continues to proliferate under the advantages it offers. Applications are becoming as varied as the imagination allows. Forest health monitoring and aerial detection survey validation continue to utilize airborne videography throughout the west. Assessment of damages to natural resources caused by disasters utilizing airborne videography is becoming more and more popular. Assessments of wildlife habitat along riparian areas and watershed stability projects are seeking benefits supplied by videography. New developments in technology will undoubtedly continue to enhance user friendliness and quality end product.

Refereces

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REMOTE SENSING IN THE NORTHEASTERN AREA

Marc A. Roberts

Forest Health Protection, USDA Forest Service, St. Paul Field Office, Northeastern Area, St. Paul, Minnesota 55108

The Northeastern Area State and Private Forestry has been involved in the remote sensing field for many years. There are historical aerial sketchmaps, oblique aerial slides, and photos dating back to the 1950's. In recent years, the remote sensing programs of the three field offices in the Northeastern Area (St. Paul, MN, Durham, NH, and Morgantown, WV) have expanded to include large format aerial photography, vertical airborne S-VHS video, and MIPS image processing systems.

Large format aerial photography has been used successfully by the St. Paul field office since the early 1980's, and more recently by the Durham field office, for many pest-related applications. The 9" x 9" color infrared aerial photography has been successfully used as a tool in detecting oak wilt, oak decline, general oak mortality, ash yellows, saratoga spittlebug damage, hemlock mortality, flood damage, and tornado and storm damage. We have also used the 9" x 9" photography for urban tree surveys and wilderness forest health assessment. True color 9" x 9" photography has been used to detect oak wilt pockets, and recently to assess forest health monitoring plots.

The three Northeastern Area field offices also have true color super VHS airborne video systems which have been tested on various projects with varying degrees of success. The successful tests of the S-VHS video include the identification and mapping of gypsy moth defoliation, hemlock looper damage, documenting gypsy moth spray block success, assessing forest health conditions and assessing flood-caused mortality. Damage types that the video has been unsuccessful in capturing include jack pine budworm damage and oak wilt. These damage types can be detected using the airborne video system, but large-scale imagery necessitate narrow flight lines. Large-area blanket coverage becomes impractical. It has been our experience that the true color S-VHS airborne video system can be used for large-area blanket coverage only for detection of higher contrast pest damage such as gypsy moth defoliation and hemlock looper damage. Lower contrast damage like jack pine budworm can be captured, but only at such a large scale that blanket type coverage of large areas becomes impractical.

The most recent addition to the Northeastern Area's remote sensing capabilities is the MIPS image processing system. Each of the three field offices recently acquired the MIPS system which will allow us to digitally store and manipulate aerial video and photography as well as satellite data. This system should enhance our remote sensing capabilities in general and make our video system a much more practical and useful tool.

MORGANTOWN FIELD OFFICE AIRBORNE VIDEO PROGRAM

John R. Omer

Forest Health Protection, Morgantown Field Office,
State and Private Forestry, USDA Forest Service,
Morgantown, West Virginia 26505

Our office assists six states, the District of Columbia, three National Forests, and over 150 other federal sites (National Parks, Wildlife Refuges, National Monuments, military bases,...etc.) with their insect and disease problems. We provide aerial surveys, aerial photography and videography, and expertise with on-the-ground surveys and verification.

The aircraft I use most often for videography is a Piper Aztec. This plane provides an excellent combination of twin engine safety and speed, and affordable cost for operation. I primarily use an installed Loran Northstar unit for navigation, usually flying straight lines point-to-point.

I've used two methods for determining latitude and longitude for flight lines. The first and most often used method is simply working straight off a 7.5 minute topographic quadrangle. The second is using georeferenced maps in Arc View, and having the computer determine the coordinates.

Following are some examples of video missions I have flown, tornado swath tree regeneration, stream corridors for the Wild and Scenic River Program, tree mortality, crop tree release plot documentation, river ice cover (impact on bald eagle activity), and forest pest surveys--gypsy moth, elm spanworm, cherry scallop shell moth, hemlock woolly adelgid, and forest tent caterpillar.

SOUTHERN REGION AIRBORNE VIDEO SUMMARY

Richard A. Spriggs

Forest Health, Alexandria Field Office, Southern Region,
USDA Forest Service, Alexandria, Louisiana 71360

Bruce Silvey

Forest Health, USDA Forest Service, Lufkin, Texas 75901

John Knighten

Forest Health, Asheville Field Office, USDA Forest Service,
Asheville, North Carolina 28808

For the past 3 years the Forest Health Field Office in Pineville, Louisiana has been using airborne video technology for southern pine beetle monitoring and spot detection in Texas, Arkansas, Louisiana and Alabama. We have been able to produce quality video imagery on hardcopy with the use of specialized software. Because of these results, our clients have expanded our use of video to include storm damage assessment, quality control checks of silvicultural practices for longleaf sites, aquatic weed encroachment on recreational lakes and monitoring of other pest damage in the Mississippi Delta and Atchafalaya Swamp in southern Louisiana, just to name a few.

Our state cooperators have expressed an interest in video and we are working together with them to develop a video mapping tool for use by the field forester.

Recently, we established a Geographical Information System (GIS) lab at the field office and are moving closer to integrating the two technologies together. With GIS and Global Positioning System (GPS) technologies, we are coming closer to building a strong, integrated program at the field office level.

We are in the process of testing a new software package together with special hardware that will enable us to produce a more accurate video product that has more precise geo-referencing capabilities, automatic video referencing to flight line position, automatic mosaicing using time encoded information and tip/tilt and roll correction capabilities. With this knowledge in hand, we will be able to significantly shorten the time needed to produce products for our clients. We are excited about the future of airborne video at this field office and Region and plan to improve our products and service in the future.

AERIAL DETECTION OF BLACK BEAR DAMAGE IN NORTHWEST ORGEON

Dave Overhulser

Forest Health Management, Oregon Department of Forestry, Salem, Oregon 97310

Introduction

In the Pacific Northwest, black bears damage conifers in the spring by peeling and eating the bark. When the entire circumference of the bole is peeled, the tree will die. Partial peeling can reduce the growth rate and vigor, introduce decay organisms, and also cause mortality if enough of the circumference is damaged. During 1988 and 1989, industrial landowners, federal land management agencies, and the Oregon Department of Forestry supported aerial surveys coupled with extensive ground sampling to define the extent and severity of bear damage on 2.4 million acres of forest land. The areas chosen for the project were the northern Coast Range and a low-elevation portion of the west-central Cascade Range. The following is a brief summary of the methods and findings of these surveys.

Methods

The aerial survey was flown at approximately 1,000 feet above the forest canopy in a twin engine Partenavia aircraft with a pilot and two observers. Average air speed was 90 miles per hour and survey lines were oriented north/south at 3-mile intervals. Potential locations of bear damage were based on the presence of foliage color indicating dead or dying trees. When observers detected dying trees, a figure or polygon was drawn on a map showing the location and number of damaged trees. Observers did not attempt to distinguish bear-damage trees from trees damaged by other agents. The 1988 aerial survey was flown in late September and October, while the 1989 survey was flown in June.

Ground surveys were conducted in both years to verify that polygons drawn by aerial surveyors contained bear damage and to measure the extent and severity of the damage. Sample polygons were randomly selected and data collected on the species, age, and size of trees as well as the percent of the circumference debarked. The 1989 ground survey sampled tree damage in polygons from an equal number of thinned and unthinned Douglas-fir stands.

Results

Timing of aerial surveys - Late May through June is the preferred time of year to detect bear damage with aerial surveys in western Oregon. During the fall surveys, aerial observers were hampered by a low sun angle and accompanying shadows. In addition, the fall foliage colors of hardwoods contounded the detection of bear damage in conifers.

Timing of bear damage and change in crown coloration - A majority of bear-damaged trees (those with red/brown foliage) detected by the aerial survey in June 1989 had been *completely* girdled in the spring of 1988. A small proportion of trees completely girdled in the spring of 1989 or 1987 also had red/brown foliage in June 1989. A June aerial survey for bear damage detects crown color changes from damage occurring over several years, but predominantly in the spring of the previous year.

Percent of polygons with bear damage - Of the 100 polygons ground-checked in 1988, 74 percent contained bear damage. In 1989, 147 polygons were ground-checked and 76 percent were found to contain bear damage.

Number of acres with bear damage - The average size of the 111 polygons ground checked for bear damage in 1989 was 30.57 acres (standard deviation = 43.3), and ranged from 1 to 280 acres. Assuming 76 percent of all polygons mapped contained bear damage, it was estimated that 1,593 polygons in the 2.4 million acre survey had bear damage. The total area represented by these polygons was 48,698 acres.

Bear damage in thinned vs. unthinned stands - Over the entire survey area, 79 percent of the polygons with bear damage were in thinned stands, and 72 percent of the polygons drawn in unthinned stands contained trees with bear damage. In the Coast Range, the proportion of polygons with bear damage was the same in thinned and unthinned areas. In the Cascades, however, 93 percent of the thinned polygons had bear damage, while only 44 percent of the unthinned polygons had bear damage.

Tree species preference by bears - Seven conifer and four hardwood species were represented in polygons containing bear damage. Douglas-fir was the most frequently damaged species. True fire, Sitka spruce, western hemlock and incense cedar showed some damage. Of four hardwood species examined, only red alder was occasionally damaged by bears.

Severity of damage on individual trees (percentage of bole circumference peeled) - Of 1,463 ground-checked conifers that were damaged by bears, one-third (33.2 percent) were completely peeled and two-thirds (66.8 percent) were partially peeled. For every tree killed by bears, two others were damaged.

Age class of bear-damaged trees - While bear damage occurred in nearly all age classes of trees, there was a clear concentration of damage in the 16- to 25-year age class. Bear damage was not found in trees less than 12 years old.

Diameter of bear-damaged trees - On the average, the diameter of bear-damaged trees was 2.7 inches larger than undamaged trees. The difference was significant at the .01 level. Bears apparently damage the fastest growing trees on the site.

A detailed discussion of the survey methods and results can be found in Forest Health Report No. 90-1, available from Forest Health Management, Oregon Department of Forestry, 2600 State Street, Salem, OR 97310.

OFF PLOT MONITORING

David R. Bridgwater

Forest Insects and Diseases, Natural Resources,
USDA Forest Service, Portland, Oregon 97208

The Environmental Protection Agency, in cooperation with other Federal and State Agencies, has developed a program to monitor the Nation's forest health. The primary information base will be gathered on fixed plots identified on a systematic grid covering the United States. A second level of monitoring will be data gathered off these plots. The "off plot" data can be compiled from any other information source, but they need to have a measure of accuracy. The aerial insect detection surveys that are flown each year have been proposed as one such source of data.

Each Region or group of States will develop their level of reporting accuracy, and confidence limits. It is anticipated that periodically each area will be expected to verify that these standards are being met. An example of how this could be accomplished would be to ground check a percentage of the polygons and compare the results to the aerial survey reporting data. While such quality assurance measurements would be expensive in both dollars and personnel, it is anticipated that funding for this activity would be provided by EPA, and would not be required until the funds are made available.

AERIAL SURVEYS: QUALITY, CREDIBILITY, VALUE - IS IT POSSIBLE?

Tim McConnell

Forest Pest Management, Missoula Field Office,
USDA Forest Service, Missoula, Montana 59807

Variability Between Sketchmappers

Duplicated Survey Flights

During the 1992 and 1993 field seasons in the Northern Region, three survey flights were duplicated over the same area. These duplications occurred because, (1) the area (125,000) on the western portion of the Priest River Ranger District, (the old Kaniksu National Forest) Idaho Panhandle National Forest is in Washington State and is surveyed by both the Northern Region and the Pacific Northwest Region, and (2) a portion (175,000 acres) of the Phillipsburg Ranger District, Deerlodge National Forest was surveyed 2 days in a row by different observers due to coverage miscommunication. All three of these duplications provided an opportunity to compare different observers' sketch maps of the same area, since they were done at nearly the same time and similar tree conditions should have existed. The terms sketchmapper and observer are used interchangeably in this paper.

Survey Map Processing

Each of these three pairs were digitized and the data summarized to make a comparison between the maps. The three pairs will be referred to as the 1992 Kaniksu, the 1993 Kaniksu and the 1993 Deerlodge. The spruce budworm polygons and the hail polygon were visited on the ground during routine follow-up ground checks. None of the polygons were ground checked to accurately determine which polygons were correct. This comparison is not to prove which observer made the right call, but to show two different data sets for the same survey area.

Map and Data Comparisons

After looking at the maps and the data tables, there appears to be a high degree of variation between the observers.

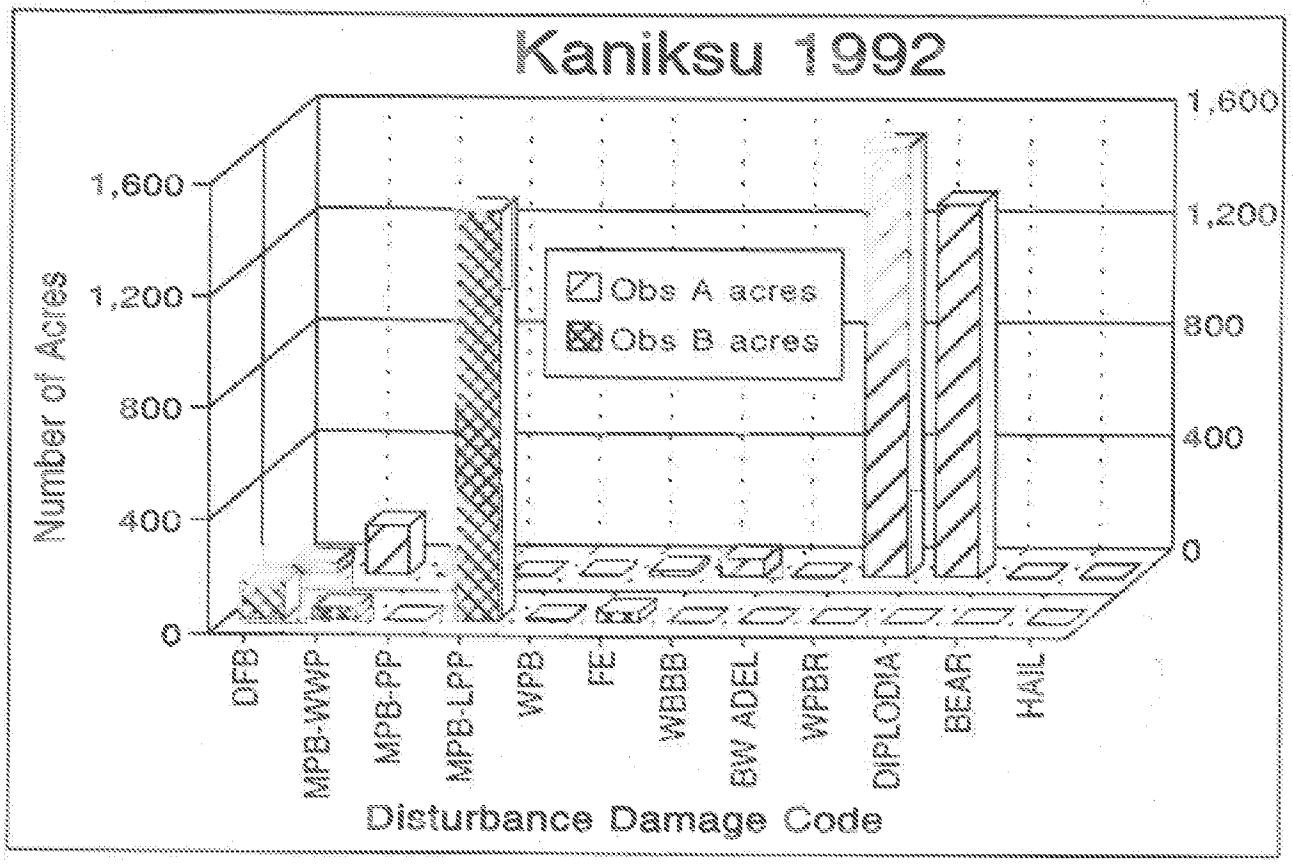
For the 1992 and 1993 Kaniksu, white pine blister rust and diplodia were either, not considered by Observer B or not observered by Observer B. It is possible that much damage was observed by both observers but given different attributes. To detect dead, mature western white pine and to determine if blister rust or mountain pine beetle was the primary tree killer from the air is at the least challenging.

For the 1993 Deerlodge, the primary difference was the occurrence of western spruce budworm defoliation on Observer B's map and no occurrence of western balsam bark beetle damage to subalpine fir. Subsequent ground checks of the budworm polygons showed that no 1993 defoliation occurred.

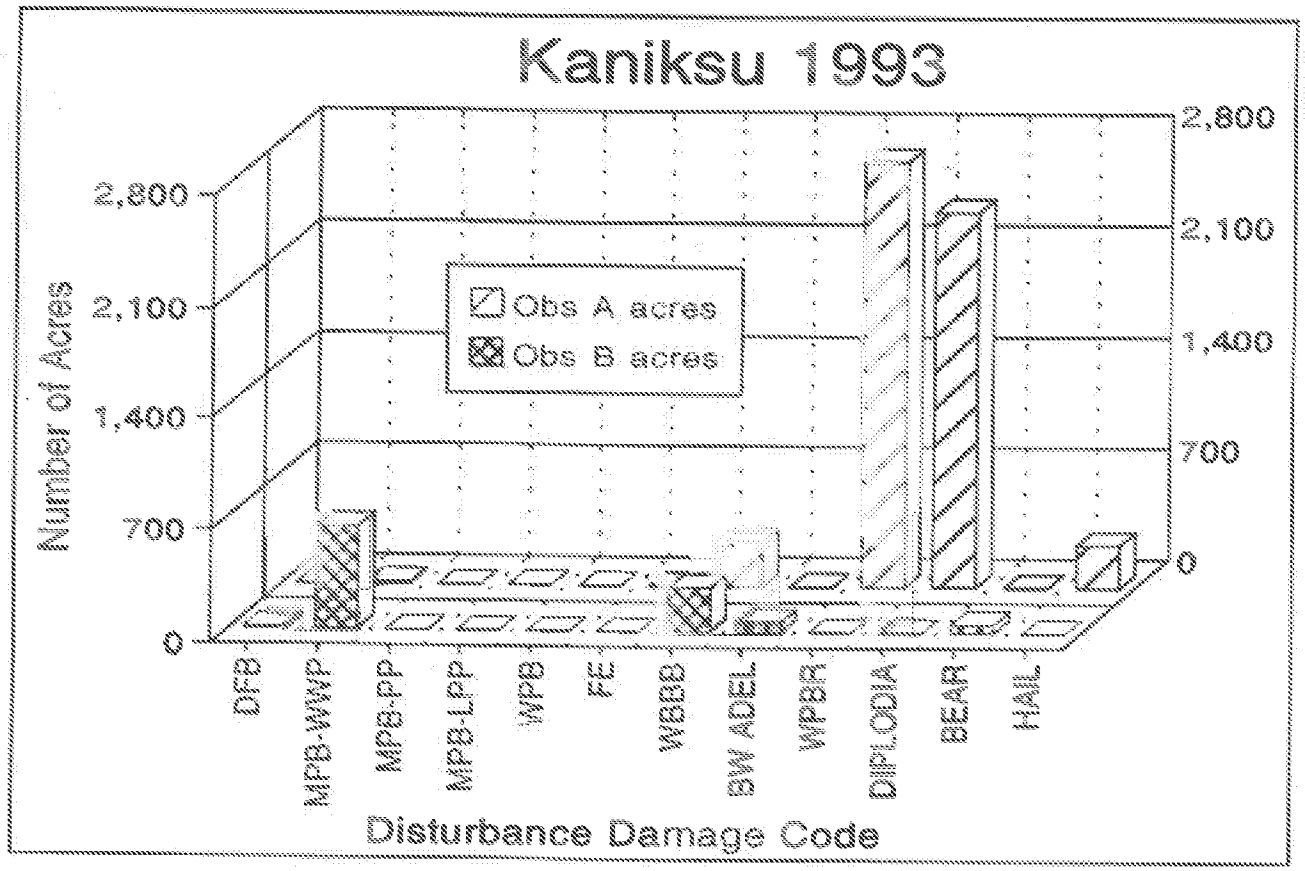
Survey Map Data Summary Tables

1992 Kaniksu

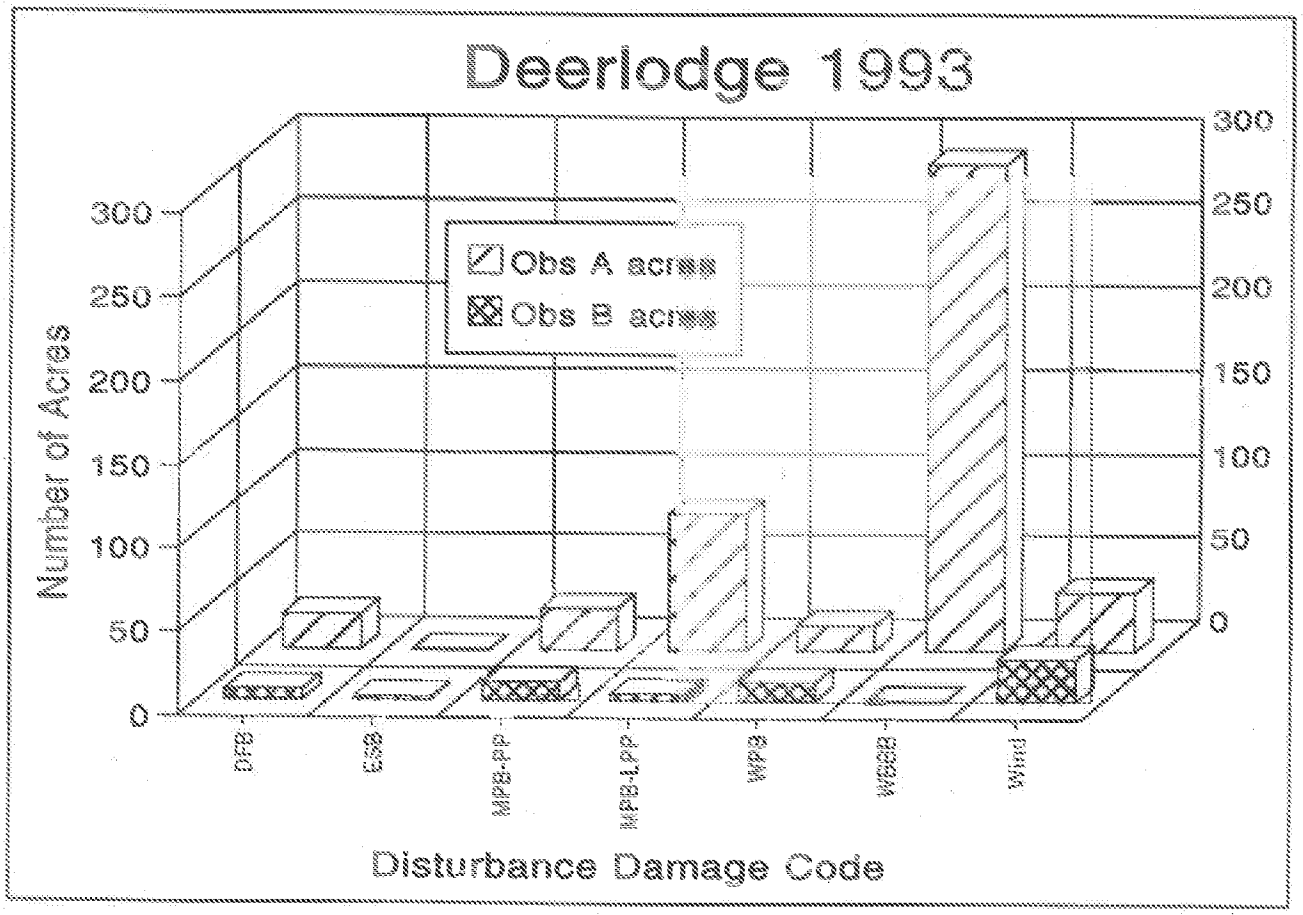
Code	Abbr.	Name	Observer A acres	Observer A trees	Observer B acres	Observer B trees
01	DFB	Douglas-fir beetle	38	42	132	70
04	MPB-WWP	Mtn pine beetle western white pine	171	102	40	55
06	MPB-LPP	Mtn pine beetle lodgepole pine	0	0	1457	1045
08	WPB	Western pine beetle	4	3	8	5
09	FE	Fir engraver	20	33	33	20
11	WBBB	Western balsam bark beetle (SAF)	60	85	0	0
50	WPBR	White pine blister rust	1532	0	0	0
68	DIP	Diplodia	1327	0	0	0



1993 Kaniksu Code	Abbr.	Name	Observer A acres	Observer A trees	Observer B acres	Observer B trees
01	DFB	Douglas-fir beetle	0	0	10	10
04	MPB-WWP	Mtn pine beetle Western white pine	13	27	635	445
05	MPB-PP	Mtn pine beetle Ponderosa pine	3	5	0	0
06	MPB-LPP	Mtn pine beetle Lodgepole pine	5	23	0	0
08	WPB	Western pine beetle	1	2	0	0
11	WBBB	Western balsam Bark beetle (SAF)	273	262	270	80
17	BWA	Balsam woolley adelgid	0	0	58	30
50	WPBR	White pine blister rust	2671	0	0	0
68	DIP	Diplodia	2355	0	0	0
-	HAIL	Hail damage	267	0	0	0
-	BEAR	Bear damge	0	0	51	30



1993 Deerlodge Code	Abbr.	Name	Observer A acres	Observer A trees	Observer B acres	Observer B trees
01	DFB	Douglas-fir beetle	21	36	6	8
02	ESB	Spruce beetle	0	0	2	1
05	MPB-PP	Engelmann Mtn pine beetle Ponderosa pine	25	24	11	12
06	MPB-LPP	Mtn pine beetle Lodgepole pine	82	136	4	3
08	WPB	Western pine beetle	15	8	11	7
11	WBBB	Western balsam bark beetle (SAF)	291	290	0	0
18	SBWL	Spruce budworm light defol.	0	0	5921	0
19	SBWM	Spruce budworm moderate defol.	0	0	10475	0
72	WIND	Wind throw	35	0	25	0



Sketchmapper Responsibility

Anyone with some aerial survey experience will tell you that every-day flying aerial survey is a humbling experience. It is no easy task to keep track of your exact location, communicate with the pilot so you are at the right altitude and in the best position for observation, detect and identify pest damage, count or estimate the number of trees, sketch the observation onto the survey map and code it, and continue to do this for 4 to 7 hours a day. But this is no excuse for not capturing the essence of the host/pest interaction in a particular drainage. A sketchmapper should do everything possible to ensure the best calls are being made, because no matter the aircraft, the flying height, the weather, the survey map base, the opportune biowindow, the survey is always going to be less than perfect.

Luxury for a survey flight is when the observer has personally been working in the outbreak area just prior to the flight. Occasionally this happens, but when each observer must cover millions of acres, this is the exception. Therefore, the observer must rely on (1) getting information from others that are on the ground, (2) flying the same area year after year to gain a sense of understanding of the elements of disturbance, (3) experience, both on the ground and aerial sketch mapping. Using past survey maps done by someone else may lead the new observer down the path of another observer's bias.

If an observer only flew one National Forest or area, the challenges of making the right call would be much easier than what many observers must do when surveying several eco-regions at less than the ideal bio-window. Still, the observer is responsible for their polygons and attributes.

Credibility comes from (1) not missing extensive damage, (2) getting the polygon in the right spot, (3) calling the tree (host) species correct, (4) knowing and calling the pest damage correctly, and (5) accurately estimating the number of trees.

Where's the value in a sketchmap that could possibly be way off the scale of acceptable accuracy? That may depend on the severity of the pest outbreak and to the intent the survey map is being used.

Aerial Survey Limitations

Understanding the limitations

The general annual aerial survey cannot be everything for everyone. Understanding how an aerial survey is conducted is important to the user of the map and data. The aerial survey has found greater value in today's world of landscape level rather than at the old stand level. The quality of the survey can also be determined by the product user. What is good enough for a Washington Office report, may not be good enough for planning a timber sale. But the timber sale planners who use aerial survey maps, know enough to use the map to get them to an area on the ground to make the determination if the area has salvage potential before planning their project. To plan a spruce budworm aerial spray suppression project by using the previous year's defoliation polygons for an Environmental Analysis boundary is absurd, but it has been done. The right way to use the defoliation polygons is to get the project planners to the area and do a more intensive delineation of the potential unit.

Scale and Resolution

How many times has a sketchmapper been flying in a fixed-wing aircraft, using a half inch to the mile recreation map and said, "If only I had a helicopter, a 1:24,000 USGS topography map and lots of time to do a really good job." There are times on special projects and surveys that this type of flying is done. But with the limitations of time, dollars and qualified, available sketchmappers, most programs rely on the traditional fixed-wing systematic survey. All surveys, all photo interpretation, all aerial videography methods are a compromise to visiting every tree out on the ground. Understanding the limitations and the degree of resolution of any remote sensing method is important to the product user as well as the polygon delineator. The reality check comes when you consider you have x amount of acres to cover in x amount of time with x amount of dollars and x amount of personnel.

Acknowledgements

Thanks to Alice Green for her additional digitizing efforts for these maps, and to Larry Stipe for the data analysis and summaries from the digitized maps.

DEFOLIATING INSECTS THAT FEED ON WESTERN HEMLOCK FROM AN AERIAL SURVEY PERSPECTIVE

Bob Backman

Washington Department of Natural Resouces,
P.O. Box 47046, Olympia, Washington 98504-7046

Roy Mask

Forest Health Management, Alaska Region,
USDA Forest Service, 2770 Sherwood, Suite 2A, Juneau, Alaska 99801

This presentation will include insect activity by western hemlock looper, hemlock sawfly, blackheaded budworm, and a combination of western blackheaded budworm and hemlock sawfly.

Western Hemlock Looper

Hemlock looper is a very difficult insect to detect unless high larval populations remove greater than 50 percent of the foliage. The larvae tend to start feeding on understory branches and work upward, often after taking a few bites from an individual needle. Most needles of western hemlock fall without fading and an aerial observer will see very little color change except for the brown from bare limbs wherever there is near total defoliation. In mixed stands, Douglas-fir and true firs will also be fed on and usually show reddish orange color. When western hemlock is less than 50 percent defoliated, the droop of the foliage and the top curled leader will be less pronounced and when observed from the ground, it often looks like Douglas-fir.

Hemlock Sawfly

Hemlock sawfly is also a difficult insect to detect. The main identifying signature is that it feeds on old foliage. Larvae tend to reduce growth rather than kill trees. Eggs are laid individually on needle margins of current year's growth, usually one per needle, and most of the population overwinters as eggs. The literature states that eggs hatch, and larvae feed from late spring to early summer. In 1982, the Washington Department of Natural Resources conducted a cooperative insecticide test using Carbaryl and Orthene. Evaluation of that test in the fall revealed that hemlock sawfly populations did not hatch until about August 7, 1982. This is a much later hatching date than reported in the literature. Fall egg counts indicated populations would decline in 1983, which we later verified. When western hemlock is defoliated by hemlock sawfly, much of the normal foliage droop disappears, and little color change is apparent other than thin crowns in trees and some yellowing. Western hemlock defoliated by hemlock sawfly can also look like Dougas-fir from ground observations because the normal branch and top droop characteristic of western hemlock tends to disappear as defoliation progresses.

Western Blackheaded Budworm

Blackheaded budworm defoliation is very easy to detect because the larvae are wasteful feeders and foliage injured by the feeding larvae turns a reddish brown color. This insect will freely feed on western hemlock, Sitka spruce and true firs. Trees of all ages can be killed, top killed or severely weakened. Moths deposit eggs singly on the underside of needles in late summer. Eggs hatch the following spring with bud development. The young larvae mine and feed in opening buds. When half grown, larvae leave the expanding buds to construct shelters. They feed on new foliage first, then they progress to the old foliage. Pupation occurs in late July to early August. Moths fly in late August, depositing eggs singly on the undersides of needles, mostly on the upper branches. Lammas growth often occurs after defoliation and can obscure some of the damage.

Western Blackheaded Budworm and Hemlock Sawfly

The concurrent defoliation of many of southeast Alaska's western hemlock stands by blackheaded budworm and hemlock sawfly, offers a special challenge to aerial sketchmappers. The signature of blackheaded budworm defoliation is a "scorched" appearance quite similar to that of western spruce budworm. The signature of hemlock sawfly is one more of foliage sparsity (older foliage) and less a matter of detecting discoloration.

On western hemlock (and Sitka spruce) in southeast Alaska, the blackheaded budworm signature is evident beginning in early July. In general, it is apparent across vast areas and will be most pronounced on higher productivity sites. The red hue begins to fade in late August as heavy rains dislodge much of the dead foliage that has been webbed together by foraging larvae.

Hemlock sawfly defoliation is less likely to exhibit a profound red hue since older needles are consumed or are clipped and fall readily from host branches. The typical signature is the bare appearance of the inner crown of defoliated host (hemlock, rather than both hemlock and spruce as with budworm) trees. This bare appearance can be confused with heavy blackheaded defoliation, especially after heavy rains in late August (or later).

Ideally, hemlock with simultaneous defoliation by blackheaded budworm and hemlock sawfly appear red on the outermost branch tips with very sparse foliage up the branches. Because of varying degrees of defoliation severity between the two insects, this "ideal" scenario is not the norm. In order to address this problem, sketchmappers have taken two courses of action:

1) data from approximately 60 defoliator plots (with beach access) are collected annually to help identify defoliating insect trends, and also to supplement aerial survey observations. Plots are accessed by floatplane and the data is collected concurrently with the aerial survey, and

2) based on results from past and current defoliator plot data, and other on-site evaluations, sketchmap observations are refined to represent the best available information.

Based on experience, areas that receive heavy defoliation concurrently by blackheaded budworm and hemlock sawfly normally experience top-kill of western hemlock after a single year's defoliation. In two instances in 1993 in southeast Alaska, hemlock mortality was also evident following a single season's defoliation.

Aerial Survey Optimum Viewing Windows for Defoliator Outbreaks in Washington and Oregon

Defoliator	*Survey Period*
Western hemlock looper	Aug. 15 - Sept. 30
Hemlock sawfly	Sept. 1 - Sept. 30
Western blackheaded budworm	July 1 - Sept. 1
Western blackheaded budworm and hemlock sawfly (Alaska)	July 15 - August 15

Major Insect Outbreaks in Washington on Western Hemlock

Year	*Insect*	*Acres*	*Treatment*
1929-32	Hemlock looper	50,000	Calcium Arsenate
1952	Hemlock looper	2,000	No Treatment
1963	Hemlock looper	70,000	Carbaryl, DDT, Bt and Phosphamidon
1967-69	Hemlock looper	3,160	Zectran and Pyrethins
1982	Hemlock sawfly	15,000	Test Carbayl and Orthene
1992-93	Hemlock looper	50,000	No Treatment

Aerial Pest Detection and Monitoring Workshop Summary

AERIAL PEST DETECTION AND MONITORING WORKSHOP

APRIL 26-29, 1994 LAS VEGAS, NEVADA

by

Tim McConnell[1], Andy Knapp[2], and Dave Bridgwater[3]

AGENDA

Tuesday, April 26, 1994

0800	Welcome to the Workshop and Introductions	Tim McConnell Andy Knapp
0820	Welcome to the Intermountain Region	Laura Ferguson
0830	Aerial Detection Surveys, Washington Office Perspective	Mel Weiss
0900	Aerial sketch mapping: A Historical Perspective	Andy Knapp
1000	Airborne Video, from the Beginning	Steve Dudley
1030	Aerial Detection Surveys and Geographic Information Systems (GIS)	Theresa Valentine
1100	Aerial Detection Survey Map Users, A Land Managers' Perspective	Rich Jeffs & Joe Frost Boise National Forest
1200	LUNCH	
1300	Aviation Safety and Aerial Surveys, An Overview	Les Miller
1330	Aerial Survey Program Presentations	See Table A
1500	Aerial Survey Program Presentations (cont)	
1600	Ecosystem Management, An Overview	Mark Jensen
1700	Daily Wrap-up	

[1]USDA Forest Service, Forest Pest Management, Missoula, MT
[2]USDA Forest Service, Forest Pest Management, Boise, ID
[3]USDA Forest Service, Forest Insects and Diseases, Portland, OR

Wednesday, April 27, 1994

Concurrent Sessions, the GIS Group and the Aerial Survey Group

GIS Working Group **Meets in breakout room**

0800	Region or Area GIS Presentations: aerial survey data capture, processing methods and generated products. Remote Sensing and GIS in the Forest Pest Management World. Forest Pest Management GIS Data Standards.	Julie Johnson and Theresa Valentine

The GIS Group rejoins the Aerial Survey Group after break

Aerial Survey Working Group **Meets in primary meeting room**

0800	Aerial Survey Program Questionnaire Results Summary	Andy Knapp
0830	Aviation Safety, Airspace Management	Bill Bulger
1030	Flight Following and Aerial Surveys, Operational Realities, A Panel Discussion	Andy Knapp Mike Plattes Bob Jennings Randy Johnson
1200	LUNCH	
1300	Aerial sketch mapping, Operational Techniques	
1300	Survey Flight Methods and Logistics	Tim McConnell
1330	Pest/Host Interactions and FPM/A&FM Interactions	Dave Bridgwater
1400	Pest Signature Challenges	Andy Knapp
	The GIS Group Returns	
1500	Airborne Video, Operational Demonstrations	
1500	Introduction and Western AirVid	Steve Dudley
1530	Midwest	Marc Roberts
1600	Northeast	John Omer
1630	South	Richard Spriggs
1700	Daily Wrap-up	

Thursday, April 28, 1994

0800	GIS Working Group Presentation of Previous Day's Discussion	Julie Johnson
0830	Data Visualization	Steve Munson
0900	Aerial Detection Surveys for Black Bear Damage	Dave Overhulser
0915	Off-site Forest Health Monitoring	Dave Bridgwater
1000	Open Discussion: How do we organize to form an effective detection and monitoring program? Future needs in aerial pest detection and monitoring survey programs?	Andy Knapp and Entire Group
1030	Entire group wrap-up Adjournment for people not participating in aerial survey training	Tim McConnell Andy Knapp Julie Johnson Dave Bridgwater
1100	Aerial Surveys: Quality, Credibility, Value - Is it Possible?	Tim McConnell
1200	LUNCH	
1345	Western Hemlock Defoliators from an Aerial Survey Perspective	Bob Backman
1500	Survey Flight Orientation Briefing and Team Selection Expected Pest Damage AirVid Mission of Survey Area	Tim McConnell Tim McConnell Andy Knapp Steve Dudley
1630	Daily Wrap-up	

Friday, April 26, 1994

Morning **Aerial Survey Flight Practicum**

0745	Meet to car pool to North Las Vegas Terminal	
0830	Preflight briefing at terminal conference room	
0900	First Survey Flight Takes Off	See Table B
1130	Final Survey Flight Takes Off	
1330	Regroup back at Alexis Park Meeting Room	
1330	Survey Flight Critique	Tim McConnell
1400	Survey Flight sketchmap Comparison Discussion	Tim McConnell
1500	Survey Map Types	Tim McConnell and Entire Group
1530	Informal Open Discussion: Flying hazards, aircraft capabilities, war stories, pest signature questions.	Tim McConnell and Entire Group
1600	Daily Wrap-up and Critique	

Table A

Presentations of Aerial Survey Programs (Tuesday, 1330 hours)

Pacific Northwest	Dave Bridgwater	Southern	Pat Barry
Southwestern	Michelle Frank	Rocky Mountain	Judith Pasek
Intermountain	Andy Knapp	Canada	Allan Van Sickle
Pacific Southwest	Sheri Smith	Kenya	J.J. Ngasi
Northeastern Area	Marc Roberts	Idaho	David Beckman
Alaska	Roy Mask and Bob Wolfe	Missouri	Susan Burks
		Northern	Tim McConnell

Table B
Flight Schedule Friday morning

0930	Flight #1	1030	Flight #4	1130	Flight #7
0945	Flight #2	1045	Flight #5		
1000	Flight #3	1100	Flight #6		

flight no.	right front sketchmapper	right rear sketchmapper	backseat senior observer	aircraft tail number
1.	B. Gardner	K. Ripley	D. Overhulser	36Z
2.	S. Wiley	S. Burks	J. Omer	82U
3.	L. Merrill	B. Schaupp	D. Beckman	69U
4.	J. Ngasi	S. Johnson	M. Roberts	36Z
5.	J. Pasek	S. Mbithi	K. Sprengel	82U
6.	S. Stelling	J. Hart	B. Wolfe	69U
7.	E. Johnson	A. Dymerski	D. Schultz	36Z

II. BACKGROUND, IMPRESSIONS, AND RECOMMENDATIONS

The workshop was designed to provide training for personnel responsible for insect and disease aerial detection surveys, both sketch mapping and videography across the country. There has been a shortage of experienced observers, a lack of a national training programs, and few opportunities for aerial survey folks to meet to discuss items of mutual interest. This, combined with a renewed interest in aerial survey programs, were the motivation factors behind the 1994 Aerial Pest Detection and Monitoring Workshop. The goal of the workshop was "to provide a forum for information sharing and technology transfer to people involved in all aspects of aerial insect and disease detection and monitoring surveys." The strong attendance from many agencies was an indication of the need.

The attendee list was a broad cross section of people interested in conducting sketchmap surveys, airborne video missions and the processing (GIS) and use of the data collected. Attendance included U.S. Forest Service Forest Pest Management (FPM) representives from every Region, many state agency people, U.S. Forest Service Aviation and Fire Management (AFM), and aerial survey program managers from the Canadian Forest Service and Kenya.

During the workshop, the group raised several aviation safety and quality control concerns. This was primarily due to many people being asked to do surveys with little training or expertise. A list of these concerns has been forwarded to the FPM Washington Office.

Many of those in attendance who have not had such formal training as AFM's "Interagency Aviation Management and Safety" course, considered the aviation safety agenda items to be very valuable. Both Lee Miller's (survey mission team concept) and Bill Buiger's (airspace management) aviation safety talks were considered workshop highlights, especially to the new observers.

A consensus was reached among the FPM attendees for the need to provide "minimum training standards" for personnel responsible for flying aerial surveys. Most units with ongoing aerial survey programs, and a long history of annual surveys, provided training primarily from "senior observer" to "junior observer." This on-the-job training is the primary method to train new observers. With some Forest Service Regions restarting their aerial survey programs, this senior/junior training method doesn't work because of the absence of a senior observer. Other units barely have enough senior observers. Therefore, a national formal training session may be necessary to meet the needs of FPM, and some states, across the country. Today, most AFM training is not specific enough for FPM.

If aerial survey programs are to be used as an effective method of pest detection and monitoring, then adequate training is a must to accomplish these remote sensing efforts in a safe manner.

There is a need to bring FPM and AFM closer together to improve survey operations and to inform AFM of other Forest Service aviation programs and needs outside of fire management.

The FPM Washington Office must play a key role to assure that AFM and FPM develop a good training plan for aerial surveys. The details of this training can be worked out with an appointed FPM and AFM team. This training should include information on contract management, aircraft performance, radio use, meteorology, survey flying method techniques, sketch mapping, etc. Additional local pest signature (recognizing pest damage) training may be needed at the Regional level.

A national aviation management training course for the 1994 field season is not possible due to the short time period prior to the aerial survey season. However, some senior observers are being detailed to Regions in need of help where possible for 1994. A 1-day aviation management and safety training course is planned in the Southwest Region prior to the survey season for 1994.

The Workshop proceedings will be compiled and published this fall or early winter. It will be distributed to all Staff Directors and workshop attendees.

Aerial Survey Program Concerns to Management

During the Aerial Pest Detection and Monitoring Workshop held in Las Vegas, Nevada, April 26 - 29, 1994, a number of items came up that we feel need immediate attention. Most of these items are serious safety deficiency-related aspects of flying aerial detection surveys, the others are survey accuracy and quality concerns. All these items of concern are due to a lack of experience and training. Aerial surveys mentioned in this document refer to both sketch mapping and airborne video missions.

Flight Safety

1. Lack of knowledge of appropriate aircraft for the survey mission.

2. Lack of knowledge of safe flight practices in mountainous terrain.

3. Lack of knowledge of aircraft contract specifications and crew responsibilities.

4. Lack of knowledge of airspace coordination.

5. Lack of understanding of Forest aviation programs to be able to obtain correct air to ground radio frequencies required for proper flight following.

6. Lack of proper radio equipment necessary for proper flight following.

7. Lack of coordination with Regional and Forest aviation groups. (FPM groups are usually not associated with A&FM groups and generally do not carry on a dialog with each other.)

Personal Safety

1. Lack of awareness of proper hearing protection.

2. Lack of knowledge of adequate mission and aircraft briefing procedures.

3. Lack of knowledge of appropriate dress and equipment that should be on board during survey missions.

Survey Accuracy and Quality

1. Lack of aerial observation experience to conduct aerial detection surveys.

2. Lack of knowledge of appropriate mission planning.

3. Lack of knowledge of appropriate survey techniques for mountainous terrain and expected insect activity.

4. Lack an understanding of the purpose for conducting the aerial survey.

Summary

This workshop was designed to allow for an interchange of ideas and procedures between Regions and States about aerial detection surveys. Also included was some introductory information for those just getting into aerial surveys. The workshop was not designed as a training session that would take untrained people

and make them into "trained observers", although in more than one case that is what was expected. What we learned was that Forest Pest Management has assigned people to do a task that results, in our opinion, in a dangerous situation to new survey personnel and risks the integrity and quality of traditional aerial surveys. Even Regions with a long history of annual aerial surveys are continually trying to build depth into their cadre of qualified observers. We would hope that in 1994 FPM personnel are not put in any compromising position in order to accomplish the task of aerial surveys.

We feel the need to quickly alert you to our concerns. We are looking for the right method to present these problems to the Washington Office. We would be glad to work with you to further develop guidelines for program safety and quality for FPM aerial surveys that may lead to minimum training standards. We intend to write a summary of the aerial survey workshop that would include our concerns, suggestions, recommendations, and critique. A workshop proceedings will also be published later this year.

III. COMMENTS FROM THE STUDENTS

I thought the workshop was great and am happy that we were able to come to closure on the need for some future training standards. The group was quite diverse in background and experience, which always makes for good interaction.

+++++++++++++++++++++++++++++++++++

Although I did not come away from Las Vegas any richer financially, I certainly gained a great deal in knowledge and contacts concerning surveys, GIS and videography. It was a great workshop whichshould be emulated (and if we do we would hope for further cross border sharing). Thanks for the invitation to participate.

+++++++++++++++++++++++++++++++++++

It was a very worth while session.

+++++++++++++++++++++++++++++++++++

This workshop was extremely important to people with very little experience doing aerial surveys, like myself. The collaborative efforts born of the workshop are to be congratulated!!! Thank you for sponsoring a workshop of such importance (sounds dramatic but my life and the lives of others are the bottom line in this work.) Look forward to participating in this workshop again-hopefully with something more concrete to contribute. Again, thank you for sponsoring a workshop so vital to our work.

+++++++++++++++++++++++++++++++++++

Here are my notes for the Aerial Detection and Monitoring Workshop. As you can tell, I thought a lot of the workshop and took alot of notes.

+++++++++++++++++++++++++++++++++++

The workshop last week was on of the best courses I have ever attended. I hope that my level of naivety didn't drag the discussion down too much for the more experienced people. I can't thank you enough for what you put into it, it made a huge difference to me.

I'd like to commend you for a very well organized and informative week. It was nice to see other doing things with videography. Steve Dudley and I have been communicating and sharing information about specific camera systems and I'll probably be purchasing some forward camera and monitoring equipment due to the information he gave me. The international visitors were very interesting and all of the other presenters did a very good job. I hope to see this workshop held again in the future.

+++++++++++++++++++++++++++++++++++

Enjoyed the meeting, we need to do it at least every other year. The only negative thing was on Wednesday afternoon. The talks on airborne video go repetitious. There was a lot of positive ideas and discussions. It does look like we need to develop a training video or a sketch mappers handbook, for those new to the game. It would also help, if time permitted and survey for different regions did not overlap, for an experienced person to be along for a few days. A short detail might work.

+++

As an attendee at the workshop, it was obvious to me that the organizers had great expertise and were committed to producing reliable pest damage data in a safe manner. I was convinced that producing credible data required a skilled aerial sketchmapper trained in pest signature recognition. We in FPM frequently lack the dollars and personnel to ground truth aerial sketchmap data, and we must be able to rely on those data. An unskilled observer will produce unreliable data - not an appropriated use of taxpayer dollars.
The workshop organizers brought in speakers from outside FPM to discuss aviation safety and airspace management. This is a complex issue and is our responsibility as aerial surveyors. Finally, this may be the best workshop or short course I've ever taken. The organizers did a superb job.

+++

We're working on developing an Forest Health Management Aviation Safety Plan for R-2.

+++

The workshop has contributed valuable insights toward job performance and safe working environments among aerial detection surveyors nationwide.

+++

Found out our new Cessna 206 is outfitted with programmable radio and is cheaper than our contract planes, so our safety problems may largely be solved. I think the workshop has really helped us get a start on revitalizing our aerial survey program--thanks!!!!

+++

I really do appreciate your letting us include the GIS meeting - I think everyone who participated in that was glad we got the chance to meet and talk. I think the workshop was a great forum for lots of good discussion - plus I was really happy to meet so many other FPM folks who I'd heard of over the past few years. It sounds like there was a lot of interest in continuing to have this kind of meeting.

Here's a brief outline on my thoughts/realizations about major issues facing aerial survey programs throughout the country.

1. Identify/*Purpose*

   a. There are major differences in the purpose of aerial survey programs around the country.

For example:

WA & OR state: Major clients are timber interests. Need fine resolution, annual survey, funding source is timber related or control related.
CA, R-6 Forest Svc: Shifting from salvage/control utility to "Ecosystem" monitoring. Requires coarser resolution, less frequent flights, funding source????

If we don't understand our purpose, we won't be able to assert the importance and utility of the survey to appropriate sources of funding or targets for application.

   b. Let's look for some new uses/products/adaptations for the aerial survey (as "pest management" dries up).

How 'bout mapping fires, disturbances, habitats?
Maybe we ought to become training specialists to teach folks how to do the aerial survey work they want to do. Or like Oregon contract to survey more special projects. We could also be more involved in environmental education - training the public about disturbances, forest health impacts, etc.

2. *Safety*, WOW
Highly variable safety standards and practicies throughout the country. Much could be resolved with improved training and equipment contracts. Some people discovered that they are probably putting themselves in danger everytime they go up. Eeeekk! Serious business. Hopefully they have some concrete plans for improvement now.

3. *Training* needs exist for new aerial surveyors. People get put in planes without adequate training to accurately identify and maps trees, acres, etc. They also don't know enough to make sure safety procedures (radios, flying methods, etc) are followed sufficiently.

4. *Standards*/Quality Control
We all want to be part of high-quality credible survey programs. Improving the quality and credibility may be achieved by:

* improving surveyor *training* to be sure all sketchmappers have a certain, definable skill level.

* try to elucidate a *level of confidence (quantifiable)* for the maps we make. This may be difficult due to inherent variability in topography, forest types, weather and light conditions, damage apparency.

* improve *documentation* which accompanies maps about the specific conditions, observers, circumstances of data collection.

* improve *general documentation* about the inherent limitations of an aerial survey, so the people who are getting copies of our maps can have better understanding of how the data's collected and what to expect from it in terms of quality.

5. Desire to continue group meeting and training sessions like this one. We can learn a *lot* from each other. Some areas don't have "seniors". We all are experiencing changes in responsibilities and technologies. We need to learn from each other.

Thanks for a very helpful, enjoyable session. I learned a lot.

IV. ATTENDEES

1.	Backman, Bob	Washington DNR, Olympia, WA
2.	Barry, Patrick	USDA FS, Forest Health, Ashville, NC
3.	Beckman, David	Idaho Dpt of Lands, Coeur d' Alene, ID
4.	Bridgwater, Dave	USDA FS, FPM, Portland, OR
5.	Bulger, Bill	USDA FS, AFM, Portland, OR
6.	Burks, Susan	Missouri Dept. of Conservation, Jefferson City, MO
7.	Cain, Bob	Forestry Division, Santa Fe, NM
8.	Dudley, Steve	USDA FS, FPM, Flagstaff, AZ
9.	Dymerski, Alan	USDA FS, FPM, Ogden, UT
10.	Ferguson, Laura	USDA FS, SPF, Ogden, UT
11.	Fisher, Scott	USDA FS, Toiyabe NF, Carson City, NV
12.	Frank, Michelle	USDA FS, FPM, Flagstaff, AZ
13.	Frost, Joe	USDA FS, Boise NF, Boise, ID
14.	Gardner, Brian	USDA FS, FPM, Boise, ID
15.	Halsey, Dick	USDA FS, FPM, Boise, ID
16.	Harman, Matt	USDA FS, AFM, Ogden, UT
17.	Hart, James	USDA FS, Deschutes NF, Bend, OR
18.	Jeffs, Rich	USDA FS, Boise NF, Boise, ID
19.	Jennings, Bob	USDA FS, Toiyabe NF, Carson City, NV
20.	Jensen, Mark	USDA FS, RAWE, Missoula, MT
21.	Johnson, Erik	USDA FS, FHM, Gunnison, CO
22.	Johnson, Juli	USDA FS, FPM, Portland, OR
23.	Johnson, Randy	BLM, Las Vegas, NV
24.	Johnson, Susan	USDA FS, FHM, Denver, CO
25.	Knapp Andy	USDA FS, FPM, Boise, ID
26.	Knighten, John	USDA FS, FH, Ashville, NC
27.	Lister, Ken	USDA FS, FHM, Denver, CO

Attendees, continued

28. Mask, Roy	USDA FS, FPM, Juneau, AK
29. Mbithi, Sarah	Kenya Forest Dpt, Kenyan FHM Centre, Nairobi
30. McConnell, Tim	USDA FS, FPM, Missoula, MT
31. Merrill, Laura	USDA FS, FPM, San Bernardino, CA
32. Miller, Les	USDA FS, EAM, Juneau, AK
33. Munson, Steve	USDA FS, FPM, Ogden, UT
34. Nelson, Dave	USDA FS, AFM, Albuquerque, NM
35. Ngasi, J.J.	Kenya Forest Dpt, Kenyan FHM Centre, Nairobi
36. Norris, Rick	FPM, R-3, Albuquerque, NM
37. Omer, John	USDA FS, FHP, Morgantown, WV
38. Otwell, Gary	USDA FS, FPM, Ogden, UT
39. Overhulser, Dave	Oregon, Dpt of Forestry, Salem, OR
40. Pasek, Judith	USDA FS, FHM, Rapid City, SD
41. Plattes, Mike	USDA FS, AFM, Missoula, MT
42. Ripley, Karen	Washington DNR, Olympia, WA
43. Roberts, Marc	USDA FS, FHP, St. Paul, MN
44. Rogers, Terry	USDA FS, FPM, Albuquerque, NM
45. Roschke, David	USDA FS, MAG, Ft. Collins, CO
46. Schaupp, Bill	USDA FS, FHM, Rapid City, SD
47. Schultz, Dave	USDA FS, FPM, Redding, CA
48. Sloan, Terry	Arizona State Land Dpt of Forestry, Prescott, AZ
49. Smith, Sheri	USDA FS, FPM, Sonora, CA
50. Sprengel, Keith	USDA FS, FPM, Portland, OR
51. Sprigge, Richard	USDA FS, FH, Alexandria, LA
52. Stellings, Shelly	Bureau of Indian Affairs (FPM), Portland, OR
53. Valentine, Theresa	USDA FS, FH, Atlanta, GA
54. Van Sickle, Allan	Canadian Forest Service, Victoria, BC
55. Weiss, Mel	USDA FS, FPM, Washington, D.C.
56. Wiley, Suzanne	USDA FS, FPM, Portland, OR
57. Wolfe, Bob	USDA FS, FPM, Anchorage, AK

National Mapping Program
Technical Instructions

Standards for Digital Orthophotos

U. S. Department of the Interior
U.S. Geological Survey
National Mapping Division

1974

PREFACE

This document establishes the technical criteria to be used in production of digital orthophotos (DOQs) for USGS partners in the National Digital Orthophoto Program (NDOP) and other USGS cooperative agreements. Information in this document is integrated with other National Mapping Program Technical Instructions and specifications for data specific metadata by the Federal Geographic Data Committee (FGDC). Also defined are requirements for the collection, processing, and quality control of digital orthophoto data entered into the National Digital Cartographic Data Base (NDCDB).

CONTENTS

	Date
1. General	12/96
2. Specifications	12/96
Appendix 2-A Digital Orthophoto Header Descriptions	12/96
Appendix 2-B Example of a USGS Keyword Header	12/96
Appendix 2-C Examples of Band Storage	12/96

SUMMARY OF CHANGES

Complete revision 12/96

A complete revision of the Standards for Digital Orthophotos was undertaken to change both format and content of the digital orthophoto quadrangle (DOQ) header, revise technical standards for overedge imagery, and include color-infrared and true color DOQs as standard products. Changes from unlabeled data fields to keyword fields in the header make the information easier to understand while complying with mandatory file specific requirements of the Federal Geographic Data Committee's "Content Standards for Digital Geospatial Metadata." Editorial changes were also necessary to clarify the text. Previous changes have been incorporated in the revision.

Change 8/93 to Part 1 and Part 2

Allowable scanning resolution was increased to 32 μm. Overedge imagery beyond both the primary and secondary horizontal datum corner points can range from a 50 meter minimum to 300 meter maximum. These changes facilitated the participation of additional cooperators in the DOQ cost share program, yet ensured that DOQs continued to meet National Mapping Division's needs for digital line graph revision. Additional header metadata was required to describe compressed data.

First USGS National Mapping Program Standard for Digital Orthophotos was released in July, 1992.

LIST OF PAGES

A complete and current copy of the preliminary pages of "Standards for Digital Orthophotos" consists of the pages (and most recent creation or revision dates) listed below.

Page	Date	Page	Date	Page	Date
1-ii	12/96				
1-iii	12/96				
1-iv	12/96				
1-v	12/96				

National Mapping Program
Technical Instructions

Part 1
General

Standards for
Digital Orthophotos

U.S. Department of the Interior
U.S. Geological Survey
National Mapping Division

1979

CONTENTS

Page

1. General 1-1
   1.1 Definitions 1-1
   1.2 Objectives 1-2
   1.3 Product Description 1-2
   1.4 Sources 1-3
   1.5 Digital Orthophoto Structure and Format 1-4
References 1-6

LIST OF PAGES

A complete and current copy of Part 1 of "Standards for Digital Orthophotos" consists of the pages (and most recent creation or revision dates) listed below.

Page	Date	Page	Date	Page	Date
1-ii	12/96				
1-iii	12/96				
1-1	12/96				
1-2	12/96				
1-3	12/96				
1-4	12/96				
1-5	12/96				
1-6	12/96				

Standards for Digital Orthophotos
Part 1: General

1. GENERAL

1.1 DEFINITIONS

The terms "digital orthophoto" and "DOQ" are used throughout this document to refer to both the 1-meter ground resolution quarter-quadrangle digital orthophoto (3.75- x 3.75-minutes in extent) and the one or two-meter ground resolution quadrangle digital orthophoto (7.5- x 7.5-minutes in extent). Although the primary digital orthophoto of concern is the 1-meter quarter-quadrangle, "DOQ" will refer to both the quarter-quadrangle and quadrangle digital orthophotos unless otherwise noted. Ground resolution, for DOQs, is synonymous with ground sample distance (GSD). The terms one and two-meter ground resolution refer to the distance on the ground represented by each pixel in the x and y components. They do not infer the minimum distance that can be detected between two adjacent features, or the minimum size of a feature expressed in size of objects or distances on the ground. The term gray-scale refers to an 8-bit image having up to 256 gray levels. Black and white refers to gray-scale images from panchromatic film while monochrome refers to a gray-scale image containing light from one wavelength band (red, green, blue, or infrared).

Digital orthophoto - A digital image that has the properties of an orthographic projection. It is derived from a digitized perspective aerial photograph or other remotely sensed image data by differential rectification so that image displacements caused by camera tilt and terrain relief are removed.

Orthophoto chips - A digital orthophoto may be made up of several images mosaicked together to form the final image. Each separate piece of the mosaic that contributes to the final image is called a "chip".

National Aerial Photography Program (NAPP)- A multiple agency program coordinated by the USGS that provides panchromatic and color infrared coverage of the United States at 1:40,000 photo scale.

National High Altitude Aerial Photography Program (NHAP) - A multiple agency program coordinated by the USGS that acquired 1:80,000 photo-scale panchromatic and 1:58,000 photo-scale color infrared photography of the 48 conterminous United States from the years 1980-1987.

1.2 OBJECTIVES

The U.S. Geological Survey (USGS) is designated as a lead Federal agency for the collection and distribution of digital cartographic data. The standards specified in this document pertain to the collection, processing, archive, and quality control of digital orthophoto data. Data produced to this standard will be archived in the National Digital Cartographic Data Base (NDCDB).

The U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), the Farm Services Agency (FSA), the U.S. Forest Service (USFS), and the U.S. Geological Survey, National Mapping Division (NMD) are partners in the National Digital Orthophoto Program (NDOP). The program was created to ensure that each agency's digital orthophoto requirements are met, and to serve the needs of the broader user community for digital imagery data. The NRCS uses digital orthophotos as a common base map to facilitate the collecting, organizing and sharing of natural resource data at county field offices. The FSA uses digital orthophotos to assist in tracking producer records at county field offices. The Forest Service employs digital orthophotos as a means to more accurately inventory the national forests. NMD extracts digital base category data directly from digital orthophotos. The Standards for Digital Orthophotos supports these orthophoto requirements. Given that the requirements and technologies involved in producing digital orthophotos will remain dynamic for some time, the Standards for Digital Orthophotos outlines many key dependencies involved in producing digital orthophotos and, in some cases, alternative methods of production.

This document also provides USGS components with guidelines for performing quality control and acceptance of digital orthophoto data into the NDCDB. Data generated by NRCS, FS, NMD and other Federal agencies, or procured from the private sector, must conform to this standard, to be accepted for entry in the NDCDB.

1.3 PRODUCT DESCRIPTION

A digital orthophoto is a geo-referenced image prepared from a perspective photograph, or other remotely-sensed data in which the displacement within the image due to sensor orientation and terrain relief has been removed. Orthophotos combine the image characteristics of a photograph with the geometric qualities of a map. They serve a variety of purposes, from interim maps to field

references for earth science investigations and analysis. The digital orthophoto is useful as a layer of a geographic information system and as a tool for revising digital line graphs. Image processing algorithms can be applied to the image data to support planimetric image classification, three-dimensional modeling, and many other spatial applications. A digital orthophoto, as described in these standards, can be produced from any scale of photography. However, the program is oriented primarily toward the production of 1-meter gray-scale and color-infrared digital orthophoto quarter-quadrangles from 1:40,000-scale National Aerial Photography Program (NAPP) or NAPP-like photography. Production of one or two-meter digital orthophoto quadrangles will be primarily supported by mosaicking digital orthophoto quarter-quadrangles. Presently, hard-copy outputs from the digital orthophotos include 1:12,000-scale orthophoto quarter-quadrangles and 1:24,000-scale orthophoto quadrangles.

The digital orthophoto is created by scanning an aerial photograph transparency (diapositive) with a precision image scanner. The scanned data file is then digitally rectified to an orthographic projection by processing each image pixel through photogrammetric space resection equations. This process requires, as input, ground control points acquired from ground surveys or developed in aerotriangulation, conjugate photo-coordinates of ground control, camera orientation parameters, and a digital elevation model (DEM). The rectified digital image is then archived on suitable digital storage media with a keyword-based informational (metadata) header affixed to the beginning of the digital image.

1.4 SOURCES

The procedures and instrumentation used for production of digital orthophotos vary, depending on the systems available. Currently, NAPP or NAPP-like photography is the primary source used for the production of digital orthophotos by the USGS. NAPP photographs are quarter-quadrangle centered (3.75 minutes of longitude and latitude in geographic extent) and are exposed at a nominal flying height of 20,000 feet above mean terrain with a 6-inch (152.4 mm) focal-length camera (photo scale = 1:40,000). A quadrangle (7.5-minute) digital orthophoto is produced either by mosaicking 3.75-minute digital orthophotos or digital orthophoto chips or by generating the digital orthophoto from 1:80,000 photo-scale black and white photography from the National High Altitude Aerial Photography Program (NHAP). Color-infrared and natural color photographs may be used as a source

for digital orthophotos. Black and white DOQs may be generated from CIR and natural color source. Other aerial photographic or digital sources may be used in the future.

The photography is scanned with an aperture that can be adjusted between 7.5 and 30 micrometers (μm), depending upon the image scanner and desired output ground/pixel resolution. For example, an aperture between 25 and 30 μm yields a reasonable compromise between file size and adequate image resolution to support the present digital orthophoto program requirements. A 9 by 9 inch (240 mm square) black and white aerial photograph scanned with an aperture of 25 μm yields approximately 88 megabytes (MB) of raw data. Using 1:40,000-scale photographs, a 25 μm scan equates to a ground sample distance of 1 meter. A black and white quarter-quadrangle digital orthophoto generated and cropped from a 240- by 240-millimeter photograph, scanned at 25 μm, with the requisite overedge and header produces a rectified file between 45-50 megabytes.

1.5 DIGITAL ORTHOPHOTO STRUCTURE AND FORMAT

The line length of DOQs varies from file to file. The standard, uncompressed grayscale DOQ format contains an ASCII header (metadata) followed by a series of 8-bit image data lines. The keyword-based, ASCII header may vary in the number of data entries. The header is affixed to the beginning of the image and is composed of strings of 79 characters each ended with a newline character. Each keyword string contains information for either identification, display, or registration of the image. Additional strings of blanks are added to the header so that the length of a header line equals the number of bytes in a line of image data. See Part 2: Specifications, 2.10 Archive and Distribution Format.

The orientation of image data is by lines (rows) and samples (columns). Each line contains a series of pixels ordered from west to east. The order of the lines is from north to south. Digital orthophotos are archived and distributed so that when displayed on a computer graphics terminal, the projection grid north is at the top of the screen.

The standard DOQ format is either a 3.75-minute quarter-quadrangle or 7.5-minute quadrangle and is black and white, color-infrared (CIR), or natural color image. Both quarter-quadrangle and quadrangle DOQs contain overedge imagery. The 3.75-minute quarter-quadrangle DOQ has a ground pixel distance of 1 meter while the

7.5-minute quadrangle has a one or two-meter ground pixel distance. The digital orthophoto is in the Universal Transverse Mercator (UTM) coordinate system on the North American Datum of 1983 (NAD 83) for 1-meter, 3.75-minute quarter-quadrangles. Either North American Datum of 1927 (NAD 27) or NAD 83 for one or two-meter, 7.5-minute quadrangles (See Section 2.5, Datums and Coordinates) can be used.

The standard, archived, quarter-quadrangle DOQ is uncompressed and is approximately 45-50 megabytes (MB) in size. DOQs are distributed in both compressed and uncompressed format. The compressed DOQ is approximately 4-6 MB in size and is accompanied by a separate header file.

References

U.S. Geological Survey, 1986, Standards for Digital Elevation Models: National Mapping Program Technical Instruction.

U.S. Geological Survey, 1991, Standards for 1:12,000-scale Orthophoto Quarter-Quadrangles: National Mapping Program Technical Instructions, 18 p.

U.S. Geological Survey, 1992, Standards for 1:24,000-scale Orthophoto Quadrangles: National Mapping Program Technical Instructions, 20 p.

National Mapping Program
Technical Instructions

Part 2
Specifications

Standards for
Digital Orthophotos

U.S. Department of the Interior
U.S. Geological Survey
National Mapping Division

CONTENTS

Page

2. Specifications 2-1
2.1 Definitions 2-1
2.2 Geographic Extent 2-2
2.3 Collection 2-2
2.4 Processing 2-3
2.5 Datums And Coordinates 2-3
2.6 Accuracy 2-4
2.7 Ground Sample Distance 2-4
2.8 Image Radiometry 2-5
2.9 Image Mosaicking 2-5
2.10 Data Quality 2-5
2.10.1 Radiometric Verification 2-5
2.10.2 Accuracy Verification 2-5
2.11 Archive And Distribution Format 2-7
2.11.1 Header Format 2-7
2.11.2 Image Data Format 2-8
2.12 Header Data Format 2-8
2.12.1 Identification 2-10
2.12.2 Display 2-11
2.12.3 Registration 2-12
2.12.4 Other Information 2-13
References 2-34

APPENDICES

2-A Digital Orthophoto Header Descriptions 2-17
2-B Example of a USGS Keyword Header 2-28
2-C Examples of Band Storage 2-30

FIGURES

2-1 Datum Corner Points 2-4
2-2 Example of monochrome DOQ storage 2-30
2-3 Example of an RGB Orthophoto stored Band Interleaved by Line . . . 2-31
2-4 Example of RGB Orthophoto stored as Band Sequential 2-32
2-5 Example of RGB Orthophoto stored Band Interleaved by Pixel 2-33

LIST OF PAGES

A complete and current copy of Part 2 of "Standards for Digital Orthophotos" consists of the pages (and most recent creation or revision dates) listed below.

Page	Date	Page	Date	Page	Date
2-ii	12/96	2-33	12/96		
2-iii	12/96	2-34	12/96		
2-1	12/96				
2-2	12/96				
2-3	12/96				
2-4	12/96				
2-5	12/96				
2-6	12/96				
2-7	12/96				
2-8	12/96				
2-9	12/96				
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2-20	12/96				
2-21	12/96				
2-22	12/96				
2-23	12/96				
2-24	12/96				
2-25	12/96				
2-26	12/96				
2-27	12/96				
2-28	12/96				
2-29	12/96				
2-30	12/96				
2-31	12/96				
2-32	12/96				

2. SPECIFICATIONS

2.1 DEFINITIONS

Band - a range of wavelengths of electromagnetic radiation. Also, image data gathered at this wavelength range.

Band Interleaved - the ordered mixing of lines (band interleaved by line, BIL) or pixels (band interleaved by pixels, BIP) of one or more bands with corresponding lines or pixels of other bands, to form a single image file. See Appendix 2-C.

Band Sequential (BSQ) - a sequence of image bands. A band sequential file may be formed by appending bands in sequence within a single file. See Appendix 2-C.

Bilinear interpolation - the mathematical computation of an unknown value based on linear interpolation along two axes. The interpolation computes the unknown value based on the weighted average of the four nearest known values. Bilinear interpolation may be used to compute pixel values in an image or elevation values from a grid elevation model.

Brightness value - a number (normally 0-255) representing a discrete intensity gray level of a pixel in an image.

Cubic Convolution - an image resampling method using cubic polynomials.

Dodging - manipulation of the intensity of part of a photograph by selectively shading or masking.

Metadata - description of the content, quality, condition, and other characteristics of data.

Micron (μm) / Micrometer - unit of length defined to be 10^{-6} meter.

Nearest Neighbor - an image resampling method that selects the value of the nearest neighboring pixel.

Panchromatic (photography) - a term applied to photographic materials possessing sensitivity to all visible spectral colors, including red.

Resample - interpolation of pixel values based upon neighboring pixel values.

Resection, photogrammetric - three-dimensional determination of the location, attitude, or height of a camera, or of the photograph taken by that camera.

2.2 GEOGRAPHIC EXTENT

The area of coverage for a standard USGS digital orthophoto is either a quarter-quadrangle (3.75-minutes of latitude by 3.75-minutes of longitude plus overedge) or a quadrangle (7.5-minutes of latitude by 7.5-minutes of longitude plus overedge).

USGS requires overlap between adjoining DOQs to facilitate edge matching and mosaicking. The required overedge amount differs for participants in the National Digital Orthophoto Program (NDOP) and for other Federal, State and local agencies, and private entities who are not associated with NDOP but have USGS cooperative agreements.

Two specifications for image overedge exist: one for imagery produced by NDOP participants and one for imagery produced under other USGS cooperative agreements. The geographic extent for DOQs will be as follows:

- For DOQs produced under National Digital Orthophoto Program funding agreements: minimum 300 (±30) meters beyond the extremes of the primary and secondary datum corner points.

- For DOQs produced under other cooperative agreements: a minimum of 50 meters beyond the primary and secondary horizontal datum corner point extremes.

The resulting digital orthophoto is a rectangle whose size may vary in relation to adjoining digital orthophotos.

2.3 COLLECTION

NAPP or NAPP-like photography is the primary image source used for production of digital orthophotos by NMD. This does not preclude other aerial photographic or digital image sources from being used. Digital orthophotos scanned from NAPP or NAPP-like imagery (diapositives) will employ a scanning aperture no larger than 32μm for 3.75-minute DOQs and no larger than 60μm for 7.5-minute DOQs.

The ground sample distances will be 1 meter for 3.75-minute DOQs and 1 or 2 meters for 7.5-minute DOQs. All quarter-quadrangle orthophotos with ground sample distances that are less than 1 meter or greater than 1 meter but less than 1.28 meters will be resampled to 1 meter. Interpolation of data to a 1-meter ground sample distance from imagery with a ground sample distance greater than 1.28 is not allowed.

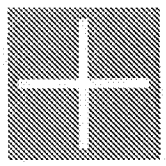
2.4 PROCESSING

Digital orthophotos require several types of inputs to produce an orthogonally rectified image from the original perspective image captured by the sensor. These inputs are the following: 1) the unrectified raster image scanned from the diapositive or directly acquired from a digital sensor, 2) a digital elevation model with the same area of coverage as the digital orthophoto, 3) the photo identifiable image and ground coordinates of ground control points, 4) calibration information about the sensor collector device and, 5) a user parameter file. These five inputs are used to register the image file to the scanner and to the sensor platform, to determine the orientation and location of the sensor platform with respect to the ground, and to remove the relief displacement from the image data.

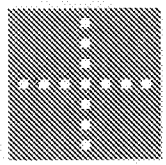
2.5 DATUMS AND COORDINATES

Digital orthophoto quarter-quadrangles will be cast on the North American Datum of 1983 (NAD 83), Universal Transverse Mercator (UTM) projection, with coordinates in meters. Digital orthophoto quadrangles will be cast on either North American Datum of 1927 (NAD 27) or NAD 83, UTM projection, with coordinates in meters. The principal horizontal primary datum for the quarter-quadrangle digital orthophoto will be NAD 83. The principal secondary horizontal datum for quarter-quadrangle digital orthophotos will be the NAD 27, the Puerto Rico Datum, the Old Hawaiian Datum, or other approved datum. The primary and secondary datums for digital orthophoto quadrangles will follow the specifications of National Mapping Division Supplemental Topographic Instruction 93-4-D, dated 8/24/93.

The four primary datum quadrangle corners will be imprinted into the image as four solid white crosses (brightness value = 255) and the four secondary datum quadrangle corners as four dashed white crosses (brightness value = 255) (see figure 2-1).



Primary Datum (NAD 83)
Corner Cross
13 by 13 solid pixels



Secondary Datum (NAD 27)
Corner Cross
13 by 13 dashed pixels

Figure 2-1 Datum Corner Points

The image header contains the primary and secondary datum corner X, Y coordinates, representing the four theoretical quadrangle corners in each datum.

2.6 ACCURACY

Digital orthophoto quadrangles and quarter-quadrangles must meet horizontal National Map Accuracy Standards (NMAS) at 1:24,000 and 1:12,000 scale, respectively. The NMAS specify that 90 percent of the well-defined points tested must fall within 40 feet (1/50 inch) at 1:24,000 scale and 33.3 feet (1/30 inch) at 1:12,000 scale. The vertical accuracy of the source DEM must be equivalent or better than a level 1 DEM, with a root-mean-square-error (RMSE) of no greater than 7.0 meters. The DOQ RMSE is the square root of the average of the squared discrepancies. These discrepancies are the differences in coordinate (X and Y) values derived by comparing the data being tested with values determined during aerotriangulation or by an independent survey of higher accuracy. All remaining inputs and processes (i.e., aerotriangulation control and methodology, scanner and sensor calibrations) used in digital orthophoto production must be sufficiently accurate to ensure that the final product meets NMAS.

2.7 GROUND SAMPLE DISTANCE

The horizontal ground resolution or ground sample distance (the area of the ground represented in each pixel in x and y components) of NDCDB digital orthophoto quarter-quadrangles will be 1 meter. This includes 3.75-minute DOQs produced by USGS and other Federal agencies participating in orthophoto production under joint funding agreements and producers of 3.75-minute DOQs participating under

cooperative agreements with the USGS. The horizontal ground resolution for 7.5-minute digital orthophoto quadrangles will be 1 or 2 meters.

2.8 IMAGE RADIOMETRY

Image brightness values will be represented by 256 gray levels and represented by a number in a range of 0-255. A value of zero will represent black and a value of 255, white; all intermediate values are shades of gray varying from black to white. Areas where the rectification process is incomplete due to missing data (i.e., lack of elevation data, gaps), will be represented with a numeric value of 128 or zero (0).

2.9 IMAGE MOSAICKING

When a mosaic of two or more digital orthophoto chips is made, the brightness values of the other chips will be adjusted to match that of the reference chip. The join lines between the overlapping chips will be chosen to minimize tonal variations. Localized adjustment of the brightness values will be done to reduce tonal differences between join areas.

2.10 DATA QUALITY

2.10.1 Radiometric Verification

During photographic reproduction of the image a limited amount of analog dodging is customarily performed to improve the image quality. The image brightness values are collected as represented on the source imagery with minimal image quality manipulation. Image brightness values may deviate from the brightness values of the original imagery due to image value interpolation during the scanning and rectification processes. Radiometric accuracy will be verified by visual inspection of the digital orthophoto with the original unrectified image to determine if the digital orthophoto has the same image quality as the source image(s).

2.10.2 Accuracy Verification

The accuracy of a DOQ is affected by several factors: photo scale, ground control, camera characteristics and the elevation model used to orthorectify the image. Therefore the producers of DOQs will ensure that all critical components have known accuracies suitable for the construction of an orthophotograph. On most standard USGS-produced DOQs, nine well-defined points are tested.

Visual verification will be done for image accuracy and completeness, to ensure that no gaps exist in either the image area or the overedge coverage. Duplicate or missing image content is an indication of poor DEM or unsuitable control and will be corrected.

Occasionally, because of DEM spikes or excessive relief in the image, an anomaly or artifact best described as an "image smear" may appear on an orthorectified image. Basically, the steepness of the terrain is such that some ground image is effectively hidden from view (e.g., on the backside of the mountain or the sides of a steep cliff). This can be especially prominent near the edges of a photograph. Where the ground is hidden from the camera position, the resampling algorithm uses the visible imagery to fill the void. For an elevation spike, the image will be warped in a region that corresponds to the DEM cell size. This sometimes results in a "smeared" or "stretched" area on the image.

When these artifacts occur, all reasonable means to correct them will be applied. Many artifacts occur in the overedge of DOQs and can usually be eliminated by rectifying the adjacent photograph to improve central perspective geometry. When a DEM spike error is detected, correcting the DEM can easily eliminate the smear. However attempting to correct stretched or smeared artifacts due to excessive relief should be weighed against how much smearing occurs, the time it takes to correct the artifact, and the features affected. It may not be cost-effective or necessary depending upon where the artifact manifests itself, e.g., outside the quadrangle boundaries. Quantifying the amount of acceptable smearing in an image can be a difficult process. Until reliable methods to predict the location and amount of smearing are established, a case by case visual inspection will determine whether to accept, remake, or reject an image. It will be necessary to remake or reject any image with smears if artifacts appear as listed below:

- In areas where man-made planimetric features are evident
- In areas where significant natural features appear
- The artifacts are of such an extent as to render the DOQ unusable

2.11 ARCHIVE AND DISTRIBUTION FORMAT

The standard DOQ for entry into the National Digital Cartographic

Data Base (NDCDB) consists of an ASCII header line(s) followed by 8-bit image data.

2.11.1 Header Format

The header (metadata) is affixed to the beginning of the image data and is composed of a variable number of ASCII-text metadata entries. To simplify in-place header editing, each entry is 80 characters long and ends with an asterisk (*) as character 79 and an invisible newline character as character 80.

The header line will be equal in length to the length of an image line. If the sum of the byte count of the header is less than the sample count of one DOQ image line, then the remainder of the header is padded with the requisite number of 80 character blank entries, each terminated with an asterisk and newline character. If the number of 80 character blank-padded entries is not an even multiple of one image line, then a partial blank padded entry, terminating asterisk, and newline character is added to the header just before the terminating 80 character keyword entry that begins with END_USGS_HEADER (see Appendix 2-B).

As an example, an orthophoto with an image line length of 6076 samples is used. The number of metadata entries is forty-five 80 character units, totaling 3600 bytes and lacking 2476 bytes to equal the image line. The header line would be padded with 30 blank-padded, 80-character entries, and one unequal entry of 76 characters, equaling a sum of 2476 blank-pads. The total byte count of the metadata would be 6076, which would then equal the length of one DOQ image line. If the header has more bytes than one line of DOQ image samples, then the header will be blank-padded to equal the samples in two DOQ image lines, and so forth.

The number of lines and keyword entries within the header is deliberately undefined to allow flexibility for accommodating header expansion and contraction within a data set and for promoting this header format on other USGS raster data.

The DOQ header begins with the keyword, BEGIN_USGS_DOQ_HEADER and is ended with the keyword, END_USGS_HEADER. Section 2.12 defines the Header Data Format and Appendix 2-A defines the file format specifications. The examples found in Appendix 2-B illustrate the structure of a DOQ keyword header complete with blank padding.

2.11.2 Image Data Format

A line of DOQ image data is composed of samples (pixels) that extend from West to East. All DOQ image lines contain the same number of samples. The total DOQ image is composed of lines ordered from North to South. The number of samples and lines composing the image is included in the metadata header affixed to the image (keyword SAMPLES_AND_LINES). Data are lines 1 - N, where N equals the number of lines of image data. See Appendix 2-C for examples of how lines are ordered and stored.

2.12 HEADER DATA FORMAT

The DOQ header contains the file-specific (inventory), mandatory element contents required by the Federal Geographic Data Committee's (FGDC) Content Standards for Digital Geospatial Metadata (6/8/94). The DOQ does not contain a full FGDC-compliant metadata file as it does not include mandatory data series (collection) FGDC elements. Those data are considered generic, i.e., common across a data type or series. Descriptions of both inventory and collection-level metadata entries for USGS DOQs may be found in the USGS Technical Instructions, Standards for the Preparation of Digital Geospatial Metadata, Part 6, Digital Orthophoto Quadrangles.

Collection level metadata files are available via the World Wide Web on the National Geospatial Data Infrastructure (NSDI), National Geospatial Data Clearinghouse. When a DOQ is produced and archived, inventory or file-specific information from its header will be appended to the collection file. The WWW address for the National Geospatial Data Infrastructure (NSDI), National Geospatial Data Clearinghouse is as follows:

http://nsdi.usgs.gov/nsdi/wais/maps/doqmet.HTML

The DOQ header is designed to include information about the image that allows a user to easily identify, display, and register other geo-referenced data to the DOQ. In addition, it contains information deemed useful but not covered in the June 8, 1994, version of the FGDC standard and therefore, the header contains element names not found in the FGDC standard. To avoid creating a header that mixed FGDC and non-FGDC element names and, to give each element a unique descriptor, DOQ header keywords generally do not match the element names in the FGDC metadata standard. However, every effort has been made to ensure that each keyword's content meets that standard. Where applicable, the equivalent FGDC element

name will be noted in the appropriate DOQ keyword description of Appendix 2-A.

The DOQ header consists of N number of entries of information relating to the 1) identification, 2) display, 3) registration, and 4) other pertinent properties of the DOQ. The USGS DOQ header must begin with an entry having the BEGIN_USGS_DOQ_HEADER keyword and end with an entry having the END_USGS_HEADER keyword. While the number of metadata entries contained in the header is undefined and may differ from image to image, the standard DOQ must contain the mandatory elements described in Sections 2.12.1 - 2.12.4. Each keyword entry in the header is 80 characters in length and terminated by an ASCII newline character included in the character count of the line.

The format of each keyword entry is as follows:

keyword data comments newline

A **keyword** is a unique string of non-blank, ASCII characters. Each keyword defines a fixed number of parameters that follow the keyword on the line. Keywords may be repeated. Other DOQ producers may employ additional keywords for their internal use but an NDCDB DOQ requires, at minimum, the mandatory keywords described in Sections 2.12.1 - 2.12.4.

Parameters are strings of ASCII characters representing values or text. Text parameters containing embedded blank characters must be enclosed in double quotation marks, e.g., "Half Moon Bay". Valid values for the parameters are described in Appendix 2-A.

Comments composed of any ASCII characters may follow the last parameters defined by a keyword. Blank characters separate the keyword from the parameters, multiple parameters, and the last parameter from the comment.

Producing agencies will place keywords in the Identification, Display, Registration, and Informational sequence shown in Sections 2.12-1 -2.12.4.

A keyword header entry is composed of 80 characters including the newline character as character 80. DOQ producing agencies will put an asterisk (*) in column 79 to help in-place editing of the header.

2.12.1 Identification

Data grouped under the Identification section hold the minimum elements required for uniquely identifying the image, including the geographic coverage of the image, the quadrangle name and 3.75-minute quadrant (assuming a digital orthophoto quarter-quadrangle rather than a digital orthophoto quadrangle) within the 7.5-minute quadrangle, and the production date of the DOQ.

BEGIN_USGS_DOQ_HEADER
The USGS DOQ header begins with the keyword BEGIN_USGS_DOQ_HEADER. It identifies the data as a USGS DOQ and begins the header.

QUADRANGLE_NAME
This is the name of the DOQ as designated by the Geographic Cell Names Data Base. The 3.75-minute quarter-quadrangle cell name is based upon the 7.5-minute cell name followed by the appropriate directional quadrant, specified as NE, NW, SW, or SE that is the parameter for the keyword QUADRANT (see below). A 7.5-minute quadrangle name may contain a directional quadrant as part of their proper quadrangle name.

QUADRANT
The 3.75-minute quadrant directional, either NW, NE, SE, or SW. See QUADRANGLE_NAME keyword description. A quadrant entry is not applicable to 7.5-minute orthophotos.

WEST_LONGITUDE
The western-most boundary of the 3.75- or 7.5-minute quadrangle excluding the overedge. USGS DOQs possess approximately 300 meters of overedge imagery beyond the primary and secondary datum corners, whichever is larger, to facilitate edge matching and mosaicking. These bounding coordinates define the extent of the 3.75- or 7.5-minute quadrangles, not the extent of the entire image.

EAST_LONGITUDE
The eastern-most boundary of the 3.75- or 7.5-minute quadrangle excluding the overedge.

NORTH_LATITUDE
The northern-most boundary of the 3.75- or 7.5-minute quadrangle excluding the overedge.

SOUTH_LATITUDE
The southern-most boundary of the 3.75- or 7.5-minute quadrangle excluding the overedge.

PRODUCTION_DATE
The date the DOQ was produced.

2.12.2 Display

Header content under the Display section contains data necessary for displaying the image. With this information, a user with the suitable viewing software and hardware can display the DOQ.

RASTER_ORDER
The raster data order. The data will be organized by line, each line containing a series of pixels from west to east. The order of lines will be from north to south.

BAND_ORGANIZATION
The default storage formats for digital orthophotos are as a **"Single file"** for gray-scale images and band interleaved by pixel (**BIP**) for 3-band color infrared images, natural color or multiple-band images. Eight-bit single band color images from natural color or CIR RGB images and 24-bit RGB images reconstituted from 8-bit composite images are not acceptable.

BAND_CONTENT
The defaults for band types and storage sequence are **BLACK&WHITE** for images from panchromatic film or single file gray-scale produced by combining the bands from color source images. For multiple-band DOQs, the BAND_CONTENT keyword is repeated for each band with one parameter per band in the band order, **RED**, **BLUE**, then **GREEN**. Single band content for monochrome DOQs will be indicated by either **RED**, **GREEN**, or **BLUE**. Provision also is made in this field for various band types and combinations: e.g., separate color bands, 3-band color plus black and white. The order of colors for band storage is always red, green, blue, followed by monochrome, if applicable.

BITS_PER_PIXEL
The number of bits per sample. The default is **8** bits per pixel.

SAMPLES_AND_LINES
The number of samples (columns) and lines (rows) of data of a single band of the data set, ordered as specified in RASTER_ORDER

description.

2.12.3 Registration

Content grouped under this section are required for geo-referencing the data and geometrically aligning (registering) two or more images.

HORIZONTAL_DATUM
This keyword gives the primary horizontal datum, which for USGS digital orthophoto quarter-quadrangles, will be **NAD83**. The primary datum for digital orthophoto quadrangles will be NAD83, NAD27, or other approved datum.

HORIZONTAL_COORDINATE_SYSTEM
Provides the ground X-Y coordinate reference system of the DOQ. The USGS DOQ default coordinate system is the Universal Transverse Mercator, UTM.

COORDINATE_ZONE
The zone identifier for the horizontal coordinate system. The default for USGS DOQs would be the appropriate UTM zone number.

HORIZONTAL_UNITS
The planar distance units of the coordinate system. The default units are **meters**.

HORIZONTAL_RESOLUTION
The coordinate system resolution (that area of the ground represented by a pixel) in units specified in HORIZONTAL_UNITS. For 3.75-minute DOQs, the requirement is **1.0**.

SECONDARY_HORIZONTAL_DATUM
The secondary horizontal datum will be the former principal horizontal datum for the geographic area (i.e., **NAD27**, Old Hawaiian, Puerto Rico). The secondary horizontal datum for 3.75-minute digital orthophoto quadrangles will be either NAD27 or other approved datum.

XY_ORIGIN
Contains ground coordinates of the first pixel in the first line of data (pixel 1,1) in the primary horizontal datum and units.

SECONDARY_XY_ORIGIN
Contains ground coordinates of the first pixel in the first line of

data (pixel 1,1) in the secondary horizontal datum and units.

2.12.4 Other Information

Most of the data found in this section are required by the Content Standards for Digital Geospatial Metadata and are considered useful. Not all are necessary to identify, display, or register the image.

NATION

The Federal Information Processing Standard (FIPS) Publication 10-3 (1977) abbreviations for the names of the nation or nations of coverage: US, MX, and CA. This keyword will be repeated if a DOQ is in two countries. Only one country value is permitted per 80 character entry.

STATE

The State(s) of coverage using code specifications described in the Federal Information Processing Standard (FIPS) Publications 6-4. Each State will be coded as a 2-digit alpha code. This keyword will be repeated if a DOQ is in more than one state. Only one state value is permitted per 80 character entry.

The order of multiple States in the header will be based on the (approximated) square mileage of the States contained in the image: i.e., the State with the largest area within the image first followed by the State with the second largest area and so on. Only the States actually contained within the 3.75-minute quadrangle area are coded in the header.

NW_QUAD_CORNER_XY

Contains the primary horizontal datum ground X and Y coordinates of the NW theoretical quadrangle corner in units specified under HORIZONTAL_UNITS, Section 2.12.3.

NE_QUAD_CORNER_XY

Contains the primary horizontal datum ground X and Y coordinates of the NE theoretical quadrangle corner in units specified under HORIZONTAL_UNITS, Section 2.12.3.

SE_QUAD_CORNER_XY

Contains the primary horizontal datum ground X and Y coordinates of the SE theoretical quadrangle corner in units specified under HORIZONTAL_UNITS, Section 2.12.3.

SW_QUAD_CORNER_XY
Contains the primary horizontal datum ground X and Y coordinates of the SW theoretical quadrangle corner in units specified under HORIZONTAL_UNITS, Section 2.12.3.

SECONDARY_NW_QUAD_XY
Contains the secondary horizontal datum ground X and Y coordinates of the NW theoretical quadrangle corner in units specified under HORIZONTAL_UNITS, Section 2.12.3.

SECONDARY_NE_QUAD_XY
Contains the secondary horizontal datum ground X and Y coordinates of the NE theoretical quadrangle corner in units specified under HORIZONTAL_UNITS, Section 2.12.3.

SECONDARY_SE_QUAD_XY
Contains the secondary horizontal datum ground X and Y coordinates of the SE theoretical quadrangle corner in units specified under HORIZONTAL_UNITS, Section 2.12.3.

SECONDARY_SW_QUAD_XY
Contains the secondary horizontal datum ground X and Y coordinates of the SW theoretical quadrangle corner in units specified under HORIZONTAL_UNITS, Section 2.12.3.

RMSE_XY
Contains the relative horizontal accuracy of the digital orthophoto expressed as an RMSE in the units specified under keyword HORIZONTAL_UNITS.

IMAGE_SOURCE
This keyword identifies the image source data type; either **"Black and White film"**, **"CIR film"**, or **"Natural Color film"**.

SOURCE_IMAGE_ID
For film image sources, this keyword contains the film identification, roll, and exposure number. If more than one image is used for the DOQ, this keyword is repeated with SOURCE_IMAGE_DATE.

SOURCE_IMAGE_DATE
Contains the date of the imagery (expressed as YYYY MM DD). When the digital orthophoto is mosaicked from multiple image chips (more

than one SOURCE_IMAGE_ID), the SOURCE_IMAGE_DATE should follow the associated SOURCE_IMAGE_ID entry.

SOURCE_DEM_DATE
The production date of the source DEM. This date could be used to determine whether the DEM is from the NDCDB archive or whether it was built specifically for DOQ production. The difference between existing, archived DEMs and DEMs built just prior to DOQ production is that the archived DEMs have been fully edited to meet USGS DEM specifications while newly built DEMs may only have been partially edited. An example is a new DEM that has water bodies that have not been leveled, and therefore would not meet full DEM specifications.

AGENCY
Identifies the production mapping center or agency responsible for checking and submitting the digital orthophoto to the NDCDB.

PRODUCER
Lists the mapping center, other governmental agency, or contractor that produced the digital orthophoto.

PRODUCTION_SYSTEM
The names of the hardware and software components, including software version numbers, used to make the orthophoto.

COMPRESSION
Identifies the compression type name, version number, and decompression type name of compressed images. If the image is uncompressed, omit COMPRESSION keyword. DOQs are archived uncompressed. However, some compressed DOQs are distributed on CD-ROM.

STANDARD_VERSION
The date of the DOQ standard to which the file complies. The version date is the date on the latest change notice.

METADATA_DATE
This keyword contains the date that the metadata for the image was created or last updated.

DATA_FILE_SIZE
Indicates the size of the data set, including the keyword header, in bytes.

BYTE_COUNT
This keyword contains the total number of bytes comprising the header, including the associated blank fill.

END_USGS_HEADER
This keyword ends the DOQ header.

APPENDIX 2-A Digital Orthophoto Header Descriptions

Domain descriptions in bold and marked with an asterisk (*)indicate standard USGS DOQ values.
FGDC *Content Standards for Digital Geospatial Metadata* (6/8/94) data element name equivalents are in brackets, e.g., *[FGDC Metadata Element]*, in the Element Description column.

Keyword	Element Description		Type	Domain/Example
IDENTIFICATION				
BEGIN_USGS_DOQ_HEADER	data type identification			
QUADRANGLE_NAME	data set name *[Title]*	Quadrangle name	text[1]	7.5-minute cell name e.g. "Half Moon Bay"
QUADRANT		Quadrant		Quadrant directional if image is quarter-quadrangle NW, NE, SE, SW
WEST_LONGITUDE	western-most boundary of the 3.75- or 7.5-minute quadrangle, excluding overedge *[West Bounding Coordinate]*		compound numeric	signed degrees, minutes, seconds DDD MM SS.SSS e.g. -110 03 45.000
EAST_LONGITUDE	eastern-most boundary of the 3.75- or 7.5-minute quadrangle, excluding overedge *[East Bounding Coordinate]*		compound numeric	DDD MM SS.SSS e.g. -110 00 00.000

[1]A text data type field must be enclosed in double quotation marks if it contains spaces. If more than one text field is specified for a keyword (see COMPRESSION keyword example), each field must be enclosed in double quotation marks.

Keyword	Element Description	Type	Domain/Example
NORTH_LATITUDE	northern-most boundary of the 3.75- or 7.5-minute quadrangle, excluding overedge *[North Bounding Coordinate]*	compound numeric	DD MM SS.SSS e.g. 38 03 45.000
SOUTH_LATITUDE	southern-most boundary of the 3.75- or 7.5-minute quadrangle, excluding overedge *[South Bounding Coordinate]*	compound numeric	DD MM SS.SSS e.g. 38 03 45.000
PRODUCTION_DATE	the date the data was produced *[Publication Date]*	date	YYYY MM DD
DISPLAY			
RASTER_ORDER	raster data order *[Format Information Content]*	text	**left_right/top_bottom***
BAND_ORGANIZATION	raster data organization *[Format Information Content]*	text	***single file*** = single file BIP = band interleaved by pixel* BSQ = band sequential BIL = band interleaved by line
BAND_CONTENT	data content of each band (repeat keyword as necessary) *[Format Information Content]*	text	BLACK&WHITE RED GREEN BLUE
BITS_PER_PIXEL	bits per pixel of raster data *[Format Information Content]*	numeric	8 *

Keyword	Element Description	Type	Domain/Example
SAMPLES_AND_LINES	number of samples (columns) and lines (rows) *[Row and Column Count]*	compound numeric	SSSS LLLL e.g. 6320 7665
REGISTRATION			
HORIZONTAL_DATUM	name of primary horizontal datum *[Horizontal Datum Name]*	text	**NAD83** = North American Datum 1983* NAD27 = North American Datum 1927 WGS72 = World Geodetic System 1972 WGS84 = World Geodetic System 1984 "Old Hawaii Datum" "Puerto Rico Datum"
HORIZONTAL_COORDINATE_SYSTEM	coordinate system in which data is presented *[Horizontal Datum Name]*	text	**UTM** = Universal Transverse Mercator* SPCS = State Plane Coordinate System Geographic = geographic
COORDINATE_ZONE	coordinate system zone *[UTM Zone Number]*	numeric	1-60 = UTM zone numbers Other coordinate system zone numbers

Keyword	Element Description	Type	Domain/Example
HORIZONTAL_UNITS	coordinate system units *[Planar System Units]*	text	**meters** * feet "international feet" "survey feet" radians "arc seconds"
HORIZONTAL_RESOLUTION	coordinate system (pixel) ground distance specified in horizontal units *[Abscissa and Ordinate Resolution]*	numeric	USGS DOQ default is 1.0
SECONDARY_HORIZONTAL_DATUM	name of the secondary horizontal datum *[Horizontal Datum Name]*	text	NAD83 = North American Datum 1983 NAD27 = North American Datum 1927* WGS72 = World Geodetic System 1972 WGS84 = World Geodetic System 1984 "Old Hawaii Datum" "Puerto Rico Datum"

Keyword	Element Description	Type	Domain/Example
XY_ORIGIN	HORIZONTAL_DATUM x and y coordinates of upper left pixel in HORIZONTAL_UNITS [XY_ORIGIN does not have a FGDC metadata element counterpart but this data may be stored under *Supplemental_Information]*	*compound numeric*	e.g. 676442.0 4152645.0
SECONDARY_XY_ORIGIN	SECONDARY_HORIZONTAL_DATUM x and y coordinates of upper left pixel in HORIZONTAL_UNITS [SECONDARY_XY_ORIGIN does not have a FGDC metadata element counterpart but this data may be stored under *Supplemental_Information]*	compound numeric	e.g. 676442.0 4152640.0
OTHER INFORMATION			
NATION	FIPS PUB 10-3 two-letter nation code (repeat as necessary) *[Place_Keyword]*	text	US, CA, MX
STATE	FIPS PUB 6-4 two-letter alpha State code. (repeat as necessary) *[Place_Keyword]*	text	e.g. CA

Keyword	Element Description	Type	Domain/Example
NW_QUAD_CORNER_XY	HORIZONTAL_DATUM x and y coordinates of NW quadrangle corner in HORIZONTAL_UNITS (NW_QUAD_CORNER_XY does not have a FGDC metadata element counterpart but this data may be stored under *Supplemental_Information*)	compound numeric	e.g. 473228.05 4400096.95
NE_QUAD_CORNER_XY	HORIZONTAL_DATUM x and y coordinates of NE quadrangle corner in HORIZONTAL_UNITS (see NW_QUAD_CORNER_XY element description)	compound numeric	e.g. 478582.44 4400040.14
SE_QUAD_CORNER_XY	HORIZONTAL_DATUM x and y coordinates of NW quadrangle corner in HORIZONTAL_UNITS (see NW_QUAD_CORNER_XY element description)	compound numeric	e.g. 478563.10 4393103.58
SW_QUAD_CORNER_XY	HORIZONTAL_DATUM x and y coordinates of SW quadrangle corner in HORIZONTAL_UNITS (see NW_QUAD_CORNER_XY element description)	compound numeric	e.g. 473203.87 4393120.38

Keyword	Element Description	Type	Domain/Example
SECONDARY_NW_QUAD_XY	SECONDARY_HORIZONTAL_DATUM x and y coordinates of NW quadrangle corner in HORIZONTAL_UNITS [SECONDARY_NW_QUAD_XY does not have a FGDC metadata element counterpart but this data may be stored under *Supplemental_ Information*]	compound numeric	e.g. 473227.35 4399847.41
SECONDARY_NE_QUAD_XY	SECONDARY_HORIZONTAL_DATUM x and y coordinates of NE quadrangle corner in HORIZONTAL_UNITS [see SECONDARY_NW_QUAD_XY element description]	compound numeric	e.g. 478581.88 4399830.60
SECONDARY_SE_QUAD_XY	SECONDARY_HORIZONTAL_DATUM x and y coordinates of SE quadrangle corner in HORIZONTAL_UNITS [see SECONDARY_NW_QUAD_XY element description]	compound numeric	e.g. 478562.54 4392894.17
SECONDARY_SW_QUAD_XY	SECONDARY_HORIZONTAL_DATUM x and y coordinates of SW quadrangle corner in HORIZONTAL_UNITS [see SECONDARY_NW_QUAD_XY element description]	compound numeric	e.g. 473203.17 4392910.07

Keyword	Element Description	Type	Domain/Example
RMSE_XY	the relative horizontal accuracy of the DOQ in horizontal units *[Horizontal Accuracy Value]*	numeric	e.g. 3.2
IMAGE_SOURCE	description of the type of source data, film or digital. *[Type of source media]*	text	"Black & White film" "CIR film" "Natural Color film" other - free text
SOURCE_IMAGE_ID	source image identification (repeat as necessary; the presence of more than one source image id indicates that the DOQ is a mosaic.)) *[Title]*	text	for film source, this should include program identification, roll, and exposure number e.g. "NAPP 2370-112"
SOURCE_IMAGE_DATE	the date of the source image (repeat as necessary following SOURCE_IMAGE_ID) *[Calendar Date]*	date	YYYY MM DD
SOURCE_DEM_DATE	the date the source DEM was produced *[Calendar Date]*	date	YYYY MM DD
AGENCY	name of oversight agency *[Originator]*	text	"U.S. Geological Survey" "Western Mapping Center (WMC)"

Keyword	Element Description	Type	Domain/Example
PRODUCER	the name of the producer (USGS mapping centers will include the center abbreviation; contractors will use their organization's name) *[Supplemental Information]*	text	"Western Mapping Center (WMC)" "John Doe Mapping Company"
PRODUCTION_SYSTEM	the names of the hardware and software, including version numbers, used in the production of the DOQ *[Native Data Set Environment]*	text	free text e.g."DV1.2 3/93 OV1.1 04/93"
COMPRESSION	Compression technique and parameters: data format, format version (this keyword is present only if the data is compressed) *[File Compression Technique]*	text	line contains three fields: • compression format name • format version number • decompression name e.g."CJPEG" "JFIFV1.01" "DJPEG"
STANDARD_VERSION	the date (if the version of the standard is identified only by date) of the DOQ standard to which the file complies *[Format version date]*	date	YYYY MM
METADATA_DATE	the date the metadata were created or last updated *[Metadata Date]*	date	YYYY MM DD

Keyword	Element Description	Type	Domain/Example
DATA_FILE_SIZE	the size of the data set in bytes including header *[Native_Data_Set_Environment]*	numeric	e.g. 54198774
BYTE_COUNT	the size of the header, including the associated blank fill, in bytes [no FGDC metadata equivalent, place under *Supplemental_Information*]	numeric	e.g. 6076
END OF HEADER			
END_USGS_HEADER			

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APPENDIX 2-B Example of a USGS Keyword Header

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BEGIN_USGS_DOQ_HEADER                                                    *
QUADRANGLE_NAME "QUINCY WEST"                              3.75 or 7.5-min.name*
QUADRANT NE                      quadrant indicator if cell size = 3.75minutes*
WEST_LONGITUDE  -91  26  15.000                          signed deg., min. & sec.*
EAST_LONGITUDE  -91  22  30.000                          signed deg., min. & sec.*
NORTH_LATITUDE   40   0   0.000                          signed deg., min. & sec.*
SOUTH_LATITUDE   39  56  15.000                          signed deg., min. & sec.*
PRODUCTION_DATE 1995 07 13                                          yyyy mm dd*
RASTER_ORDER LEFT_RIGHT/TOP_BOTTOM                        video display order*
BAND_ORGANIZATION "SINGLE FILE"                 single file or BSQ, or BIL or BIP*
BAND_CONTENT BLACK&WHITE                           black&white or red green blue*
BITS_PER_PIXEL   8                                                       *
SAMPLES_AND_LINES   6076  7641                      number of columns and rows*
HORIZONTAL_DATUM NAD83                                primary horizontal datum*
HORIZONTAL_COORDINATE_SYSTEM UTM                                         *
COORDINATE_ZONE     15                           coordinate system zone number*
HORIZONTAL_UNITS METERS                                coordinate system units*
HORIZONTAL_RESOLUTION 1.0 coordinate system geometric resolu. in horiz. units*
SECONDARY_HORIZONTAL_DATUM NAD27                    secondary horizontal datum*
XY_ORIGIN   633063.000  4429328.000     coord. of upper left pixel-pri. datum*
SECONDARY_XY_ORIGIN  633079.000  4429113.000 coor.-upper left pixel-sec datum*
NATION US                                                        nation code*
STATE IL                                                      state fips codes*
STATE MO                                                      state fips codes*
NW_QUAD_CORNER_XY  633377.438  4428926.385 X-Y coords. of pri. NW quad corner*
NE_QUAD_CORNER_XY  638712.782  4429021.805 X-Y coords. of pri. NE quad corner*
SE_QUAD_CORNER_XY  638839.205  4422084.460 X-Y coords. of pri. SE quad corner*
SW_QUAD_CORNER_XY  633498.995  4421989.077 X-Y coords. of pri. SW quad corner*
SECONDARY_NW_QUAD_XY  633380.942  4428716.377 X-Y coords. - sec. NW quad cor.*
SECONDARY_NE_QUAD_XY  638716.426  4428811.800 X-Y coords. - sec. NE quad cor.*
SECONDARY_SE_QUAD_XY  638842.847  4421874.579 X-Y coords. - sec. SE quad cor.*
SECONDARY_SW_QUAD_XY  633502.497  4421779.193 X-Y coords. - sec. SW quad cor.*
RMSE_XY  0.82                                              doq horiz. accuracy*
IMAGE_SOURCE "black & white film"                 b&w, color, infra-red or other*
SOURCE_IMAGE_ID "NAPP 2231-   2"                     source image identification*
SOURCE_IMAGE_DATE 1991 03 24                    source image date as yyyy mm dd*
SOURCE_DEM_DATE 1995 07 00                                    source DEM date*
AGENCY "Western Mapping Center (WMC)"                  name of oversight agency*
PRODUCER "Western Mapping Center (WMC)"                    name of DOQ producer*
PRODUCTION_SYSTEM "DV1.2 03/93 OV1.1 04/93"     name of the production HW & SW*
STANDARD_VERSION 1996 12                                 version of DOQ standard*
METADATA_DATE 1996 7 13                  date created or changed, yyyy mm dd*
DATA_FILE_SIZE  46432792                                 data set size in bytes*
BYTE_COUNT  6076                                              header byte count*
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END_USGS_HEADER                                                                 *
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On this and the previous page is an example of an orthophoto header of a grayscale image whose line length is 6076 samples. The number of populated metadata entries is forty-five 80-character entries. This totals 3600 bytes and lacks 2476 bytes to equal the image line (6076-3600=2476). The header is padded with 30 blank-padded, 80-character entries (the blank areas followed by an asterisk (*)), one unequal entry of 76 characters, with the sum of the blank-pads equaling 2476 characters. The total byte count of the header is 6076 which equals the length of one DOQ image line.

APPENDIX 2-C Examples of Band Storage

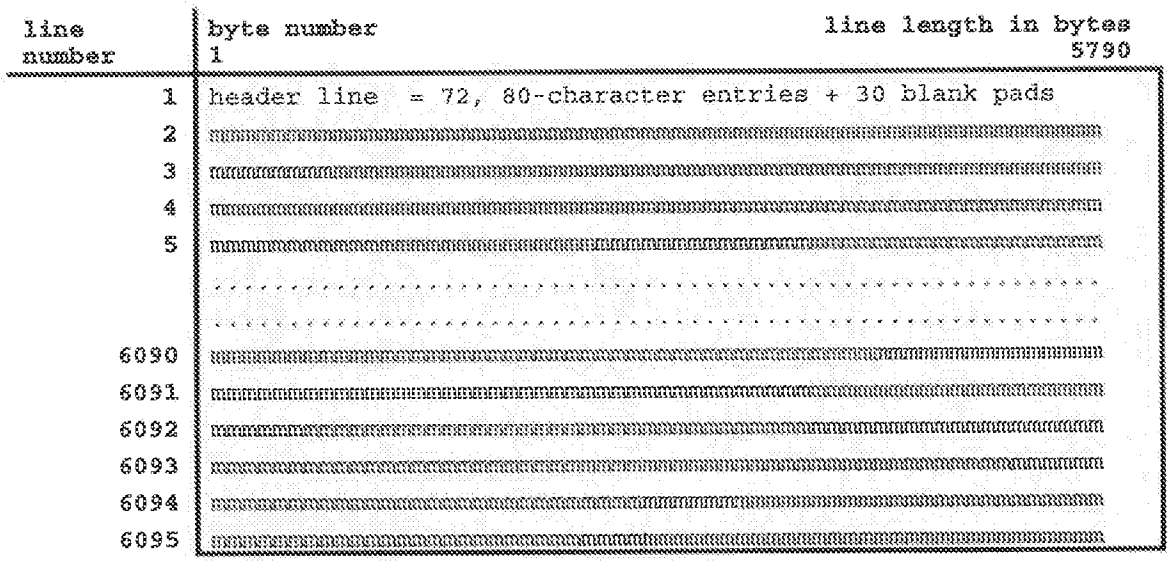


Figure 2-2 Example of monochrome DOQ storage. Example of a standard digital orthophoto stored as a simple monochrome image file consisting of 6094 image lines plus a single header line. Each line, including the header, is 5790 bytes in length. File size is 33.6 MB.

line number	byte number 1 — line length in bytes 5790
1	header line = 72, 80-character entries + 30 blank pads
2	rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr
3	ggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggg
4	bbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbb
5	rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr
6	ggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggg
7	bbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbb
	. . . . .
	. . . . .
6095	rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr
6096	ggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggg
6097	bbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbb
	. . . . .
	. . . . .
12188	rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr
12189	ggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggg
12190	bbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbb
	. . . . .
	. . . . .
18281	rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr
18282	ggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggg
18283	bbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbb

Figure 2-3 Example of an RGB Orthophoto stored Band Interleaved by Line (BIL). Each band contains 6094 lines. File size is 100.9 MB. r - red band g - green band b - blue band

line number	byte number 1 — line length in bytes 5790
1	header line = 72, 80-character entries + 30 blank pads
2	rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr
3	rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr
	. . . . .
	. . . . .
6095	rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr
6096	ggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggg
6097	ggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggg
	. . . . .
	. . . . .
12188	ggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggg
12189	ggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggggg
12190	bbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbb
	. . . . .
	. . . . .
18281	bbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbb
18282	bbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbb
18283	bbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbb

Figure 2-4 Example of RGB Orthophoto stored as Band Sequential (BSQ) with 6094 lines of each band appended to each other. File size is 100.9 MB
r - red band g - green band b - blue band

line number	byte number 1	line length in bytes 17370
1	header line = 217, 80-character entries + 10 blank pads	
2	rgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgb	
3	rgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgb	
4	rgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgb	
5	rgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgb	
	.....	
	.....	
6093	rgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgb	
6094	rgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgb	
6095	rgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgbrgb	

Figure 2-5 Example of RGB Orthophoto stored Band Interleaved by Pixel (BIP). 6094 image lines plus a header line, each 17370 bytes in length. File size is 100.9 MB.
r - red band g - green band b - blue band

References

U. S. Geological Survey, 1986, Standards for Digital Elevation Models: National Mapping Program Technical Instruction.

Federal Geographic Data Committee, 1994, Content Standards for Geospatial Metadata (June 8): Washington, Federal Geographic Data Committee

Mobile Mapping Technology for Road Network Data Acquisition [1]

C. Vincent Tao

Department of Geomatics Engineering,
The University of Calgary
2500 University Drive, NW, Calgary, Alberta, Canada T2N 1N4
E-mail: ctao@acs.ucalgary.ca

Abstract

The advancement of sensor technology enables fast and cost-effective acquisition of spatial data. This paper provides a review of the state-of-the-art development of mobile mapping technology in North America. Following a background introduction, multi-sensor integrated mapping technology is described. The key concept of direct georeferencing is given. The sensors as well as their accuracy aspects are addressed. As a system example, the VISAT™ mobile mapping system is introduced. The recent progress on automated feature extraction from mobile mapping imagery is reported. Finally, applications of mobile mapping technology are discussed.

1 Introduction

It has been demonstrated that mapping science has been steadily stepped into a digital mapping era. The core technologies of photogrammetry, remote sensing, geographic information systems (GIS) and spatial positioning are becoming fully integrated, resulting in the tremendous expansion and rapid growth of mapping markets. Modern digital mapping technology is characterized by the capabilities of ***multi-discipline combination, multi-platform compensation, multi-sensor integration and multi-data fusion.***

The multi-platform, and multi-sensor integrated technology has established a trend towards fast spatial data acquisition. Multi-sensor systems can be mounted on various platforms, such as satellites, aircrafts or helicopters, land-based vehicles, water-based vessels, and even hand-carried by individual surveyors. As a result, every vehicle or individual surveyor becomes a potential data collector, responsible for globally integrated data acquisition. The recent development of land-based mobile mapping systems represents a typical application of this integrated technology. In fact, the development of mobile mapping systems was largely driven by the transportation applications and is being further inspired by the wide implementation of Intelligent Transportation Systems (ITS) and Geospatial Information Systems in Transportation (GIS-T).

2 Development of Mobile Mapping Systems

2.1 Photo-Logging

In the 1970's, ***photo-logging*** systems were used by many highway transportation departments to monitor pavement performance, signing, maintenance effectiveness, encroachments, etc. These services are typically conducted every two or three years. Often film cameras were used to capture photos through the windshield of a vehicle (e.g., van). Inertial devices such as gyroscopes and accelerometers, and wheel counters were employed to determine the instantaneous positions of the captured photographs. Each photo was stamped with time and geographic position information. These photos were stored mainly as a pictorial record of highway performance (Birge, 1985).

Due to the poor accuracy of vehicle positioning and only a single camera configuration in these systems, the functionality of 3-D object measurement was not available. The main drawback of photo-logging is the film-based storage and processing. Accessing the photos for engineering,

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planning, legal or safety activities was time-consuming because film is fragile and the process requires costly film production. For example, Tennessee Department of Transportation (Tennessee, U.S.A.) maintains the photolog of approximately 27,000 miles of roadway in its state. All pictures were kept on film and they were only viewed by using some special viewing machines. In order to make these photos more accessible, the Department has converted its existing photolog from film to a digital format and developed a client/server based system. The system allows users to point-and-click any location along the roads and view the logging images through a desktop PC connected to the server.

2.2 Video-Logging

With the advent of the Global Positioning Systems (GPS) as well as the video imaging technologies, cumbersome photo-logging systems were replaced by GPS-based video-logging systems. It has been demonstrated by many projects that the GPS-based video-logging systems offer a fast and low-cost approach to highway inventory (Lapucha, 1990; and Schwarz et al., 1990). The collected video images can be georeferenced with respect to a global coordinate system by using continuous GPS navigation and positioning information. The turn-around time of data processing is significantly reduced since no film processing is involved. Furthermore, the digitally georeferenced video data allows quick retrieval and effective management. The capability of interpretation of highway video data is also strengthened through the use of image processing software. This approach has become widely accepted by most transportation departments. Visual inventory and feature documenting along road corridors remain the major purpose of these kinds of systems.

Due to the low resolution of video images, quantitative measurements from these images are still limited. The video images are often stored in a tape system. This may further degrade the quality of images. It is a fact that most of these systems only have a single camera configuration. Therefore, precise 3-D measurements are not possible. However, some alternative methods can be developed to provide relative measurements from a single image, such as height and offset measurements (Tao, 1997).

2.3 Mobile Mapping

The evolution of mobile mapping systems from video-logging systems was mainly contributed by the efforts of two research groups in North America, The Center for Mapping at The Ohio State University, U.S.A. and the Department of Geomatics Engineering at The University of Calgary, Canada (Bossler et al., 1991; and Schwarz et al., 1993). Compared to video-logging systems, mobile mapping systems are able to offer full 3-D mapping capabilities that are realized by using the advanced multi-sensor integrated data acquisition and processing technology (El-Sheimy and Schwarz, 1995; Li, 1997; Novak, 1995, and Tao, 1997).

A common feature of mobile mapping systems is that more than one camera is mounted on a mobile platform, allowing for stereo imaging and 3-D measurements. Direct georeferencing of digital image sequences is accomplished by the multi-sensor navigation and positioning techniques. Multiple positioning sensors, GPS, Inertial Navigation System (INS) and dead-reckoning (DR), can be combined for data processing to improve the accuracy and robustness of georeferencing. The ground control required for traditional mapping is eliminated. The systems can achieve centimeter accuracy of vehicle positioning and meter or sub-meter 3-D coordinate accuracy of objects measured from the georeferenced image sequences.

Another advantage of mobile mapping systems is that the data link to a geospatial database is easy and straightforward. The collected geometric and attribute information can be directly used to build and update a database. With the development of fast communication and image compression technologies, real-time image data link from a field mobile mapping system to an office GIS can be realized. Furthermore, such data can be disseminated and accessed through widely distributed Internet and even wireless networks.

A list of some of systems available in North America is provided in Table 1 (sources are from the literature and the website information of companies). It is worth noting that data in Table 1 could be outdated and may not be accurate due to the continuous system improvements.

Table 1. Some of video-logging and mobile mapping systems in North America

System	Developer	Positioning Sensors	Mapping Sensors	Website References
ARAN	Roadware Corp., ON, Canada	Accelerometers/IMU/ GPS	1 VHS, 2 or more CCD, Laser	www.roadware.com
DGI	Data Chromatics, Inc., USA	GPS	1 CCD	www.dcigis.com
GeoVAN	GeoSpan Corp., CO, USA	GPS/DR	8 CCD, voice recorder	www.geospan.com
GI-Eye	NAVSYS Corp., CO, USA	GPS/IMU	1 CCD	www.navsys.com
GPSVan	The Ohio State University, Columbus, OH, USA	GPS/Gyro/wheel counter	2 CCD, voice recorder	N/A
GPSVision	Lambda Tech Int'l Inc., WI, USA	GPS, INS	2 color CCD	www.lambdatech.com
ON-SIGHT	TransMap Corp., OH, USA	GPS, INS	4 color CCD	www.transmap.com
Roadview	Mandli Communications, Inc, WI, USA	GPS/IMU/Inclination Odometer/Barometer	Progressive Scan CCD	www.mandli.com
Road Radar	Road Radar Ltd., Canada	GPS	Ground Penetrating Radar, 1 Video	www.rrl.com
TruckMAP	John E. Chance and Associate, Inc., LA, USA	Multi-antenna GPS/gyro	Laser range finder, 1 Video	www.jchance.com
VISAT	The Univ. of Calgary and Geofit Inc., Canada	GPS/INS/Anti-Brake System	8 B/W CCD, 1 color SVHS	www.visat.com
VMS	Redhen Systems, Inc. CO, USA	GPS	1 CCD, voice recorder, Laser	http://www.redhensystems.com/vms/

3 Multi-Sensor Integrated Mobile Mapping Technology

A mobile mapping system consists of three components: data acquisition, information extraction and information management. In this section, the data acquisition component is described. This is the first but critical step to the development of a mobile mapping system.

3.1 Direct Georeferencing

The most important concept of mobile mapping is *direct-georeferencing*. The conceptual layout of direct georeferencing is shown in Figure 1. Direct-georeferencing refers to the determination of the exterior orientation of the mapping sensor without using ground control points and the photogrammetric block triangulation. For example, if a camera sensor is used, any captured image can be "stamped" with the georeferencing parameters, namely three positional parameters and three attitude parameters. As a result, 3-D object measurements can be achieved directly by using a photogrammetric intersection.

There are three modes for direct georeferencing, namely, stand-alone mode, integrated model and combined mode.

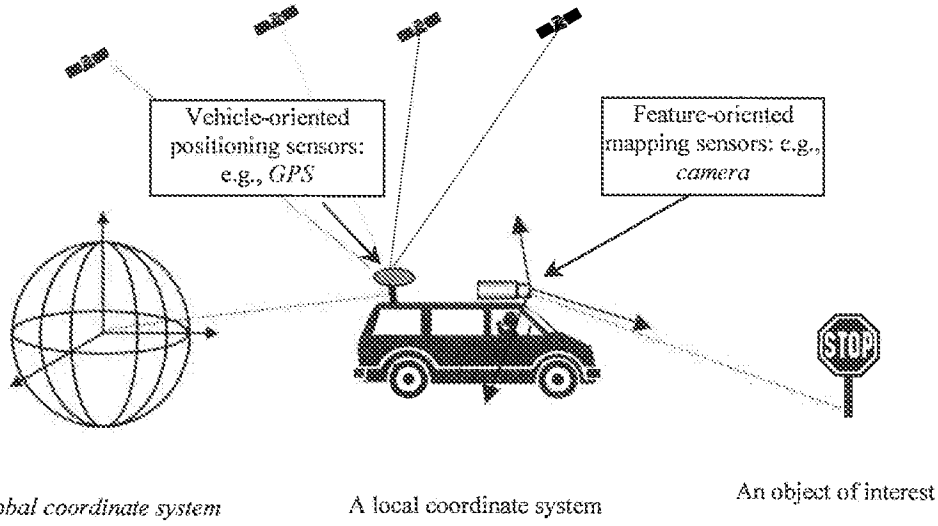


Figure 1. The concept of direct georeferencing

Stand-alone mode: Due to the unavoidable occurrences of the GPS satellite signal blockage, the use of GPS alone to provide the positional information is not reliable. Although a number of radio navigation systems as well as recent cellular positioning systems, e.g., Loran-C, CDMA-based systems, are available, they do not yield sufficient accuracies for most mobile mapping applications. The stand-alone mode for georeferencing is not a stable solution for mobile mapping. However, it has been used very often for video-logging applications where the accuracy requirement is not high.

Integrated mode: The integrated use of external inertial positioning systems is, currently, widely adopted approach for georeferencing (Schwarz and Wei, 1994; Lithopoulos, 1996; Skaloud et al, 1996; Grejner-Brzezinska, et al., 1999). Depending on the applications, different levels of integration and different ways of sensor combination can be developed, for example, GPS with INS, GPS with DR, etc. This mode will be further discussed next.

Combined mode: In the airborne photogrammetry, combined mode for georeferencing is predominately used in practice due to its high performance, reliability and economic factors. In this mode, the GPS observations and the photogrammetric observations are both combined into a triangulation block adjustment. Thus the systematic GPS errors can be controlled and corrected via the combined adjustment (Ackermann, 1996). Very few control points are required in this combined mode to solve the datum transformation. In mobile mapping systems, it is a fact that the image tie points available from the overlapped image sequences can be used to perform a strip-wise photogrammetric triangulation. Thus, the orientation parameters of the camera can also be derived. This technique can be used for quality control of georeferencing data derived from GPS/INS observations, and furthermore, to bridge gaps where the absence of the orientation observations occurs. The new georeferencing approach has been researched at the University of Calgary (Chaplin and Chapman, 1998; and Tao et al., 1999).

Direct georeferencing brings of significant benefits to the mapping procedure in terms of the rapid turn-around time of data processing and reduced cost of ground control surveys. The direct georeferencing technique makes mobile mapping feasible and has also led to the successful development of a new generation of airborne mobile mapping systems, such as airborne LIDAR mapping systems and airborne SAR systems. It is a goal that mapping would be independent of any ground control, and ultimately, mapping becomes completely autonomous.

3.2 Positioning and Mapping Sensors

The development of mobile mapping systems is featured by the use of multiple sensors as well as integrated sensor processing methods. In general, there are two primary types of sensors that are involved, namely, positioning sensors and mapping sensors:

Positioning sensors

a) Environment-dependent external positioning sensors: GPS, radio navigation systems, Loran-C, and cellular positioning devices, etc.
b) Self-contained inertial positioning sensors: INS or IMU (Inertial Measurement Unit), dead-reckoning systems, gyroscopes, accelerators, compasses, odometers, and barometers, etc.

Mapping sensors

a) Passive imaging sensors: video or digital cameras, multi-spectrum or hyper-spectrum scanners, etc.
b) Active imaging sensors: Laser range finders or scanners, and synthetic aperture radar (SAR), etc.

Other sensors such as voice recording and speech recognition devices, touch-screens, temperature or air pressure meters, gravity gauges, etc. may be of use for integration.

The positioning sensors are vehicle-oriented. They are used to determine the absolute locations of the mobile mapping platform with respect to a global coordinate system, e.g., WGS-84. While, the mapping sensors are feature-oriented. They provide the positional information of objects (features) relative to the vehicle in a local coordinate system. In addition, attributes of features can be obtained from the mapping sensors. Precise calibration is required to geometrically align the positioning sensors and mapping sensors together. Accurate synchronization (time referencing) of the sensors is also required.

3.3 Accuracy Assessment of Sensors

The choice of sensors and the effective integration of sensors is a key to the development of a mobile mapping system. Accuracy, cost, reliability, data rate, portability, power consumption as well as integratibility are the most important factors to be considered. Among of them, accuracy and cost are the primary factors for a system design and implementation.

3.3.1 Accuracy of Positioning Sensors

GPS is the most viable choice for the determination of position information due to its wide acceptance and proved performance. GPS can be operated in a variety of modes. The associated accuracies of each mode are summarized in Table 2 (Ellum and El-Sheimy, 2000).

Table 2. Position accuracy of GPS

GPS mode	*Horizontal Accuracy (2-D RMS)*	*Vertical Accuracy (RMS)*
Code Differential (Narrow Correlator, Carrier-phase smoothing)	0.75 m	1.0 m
L1 Carrier-phase RTK (Float ambiguities)	0.18 m	0.25 m
L1/L2 Carrier-phase RTK	0.03 m	0.05 m
L1 and L1/L2 Post-mission Kinematic	0.02 m	0.03 m
L1 Precise ephemeris (with Ionospheric Modelling)	1.0 m	3.0 m

With respect to the attitude determination, there are a number of options. Table 3 gives a list of possible sensors for attitude determination. The accuracies stated are for tilt angles (roll and pitch) below 20 degree. For more information regarding these numbers, one may refer to Ellum and El-Sheimy (2000), and Schwarz and El-Sheimy (1996).

In fact, only the IMU can provide all three attitude angles. For the other systems to provide all three attitude angles, they must be combined with additional sensors. Alternative to the IMU approach is to use GPS multi-antenna systems. It has been used in the airborne and ship-borne

environments where its accuracy for attitude determination has been acceptable. However, for the land vehicle based mobile mapping applications, such a multi-antenna based GPS system can not reach the acceptable accuracy level due to the fact that the baseline between the antennas is limited. Most mobile mapping systems use navigation grade IMU in order to meet the accuracy requirements. This is one of the reasons that make the initial development cost very high.

Table 3. Accuracy of sensors for determining attitude

Sensor Type	Accuracy in Roll and Pitch	Accuracy in Azimuth	Cost (USD)
Navigation Grade IMU	<0.01°	<0.03°	>$100,000
Six-Axis Tactical Grade IMU	0.25°	2°	$12,000 – 20,000
Twin Antenna GPS	0.5°-1.0°	0.75°	$2,000 – 6,000
High-Accuracy Tilt Sensor	0.05°	-	$3500
Low-Accuracy Tilt Sensor	0.25°	-	$700
Magnetic Azimuth Sensors	-	1.0°	$250
3-Axis Magnetometer Integrated with 2-Axis Tilt Sensor	0.25°	1.0°	$700-1,200

3.3.2 Accuracy of Mapping Sensors

Considering the error contribution from the imaging component alone, the positioning accuracy of object point coordinates derived from imagery is determined mainly by four factors: the object distance (Y), the baseline length (B), the focal length (f), and the mean square error of image coordinate measurements (m_{psi}). The along-track error component is the predominant error contributing to the total positioning error in mobile mapping applications. Tao (1999a) has conducted a comprehensive analysis of the achievable accuracy from a stereo imaging system. The main conclusions can be summarized as:

a) The maximum baseline length between two cameras is restricted by the desired overlap percentage; the overlap percentage is affected by the field of view angle of the camera; and the field of view angle is determined by the focal length and the camera sensing area. Therefore, a best trade-off is required for the configuration of these imaging parameters. In Tao (1999a), a method to find an optimal combination of imaging parameters was developed.

b) Under the assumption of that the manual measurement accuracy for a single image point is 0.29 pixel, the maximum camera-to-object distance is 35m if the object positioning accuracy of 30 cm is required (with a standard CCD stereo camera system). However, if the image coordinate measurement accuracy of 0.2 pixel can be achieved, the positioned object can be 50m far from the camera. Therefore, development of sub-pixel image measurement algorithms is of significant importance. The use of multiple-image matching for point measurement has been considered as an effective approach (Tao, 1997).

c) The choice of camera types is critical to overall system performance. The camera parameters such as pixel spacing, sensing area, electronic noises, data capture rate and storage requirement must be considered carefully. Cameras with small pixel spacing, pixel synchronization unit and built-in A/D converter allow for obtaining more accurate image coordinate measurements. The use of large sensor cameras will improve the overall system accuracy and permit flexibility on the configuration of imaging parameters.

An accurate calibration of interior orientation parameters, rotation angles φ (rotation around the axis Z) and the baseline is required. Based on the theoretical analysis (Tao, 1999a), the calibration accuracies of 0.3 pixel of interior orientation parameters, 0.02° for the rotation angles φ, *0.03°* for the relative orientation angle and 3.5 mm for the camera baseline have to be achieved, so that the effects of the calibration errors onto the total system positioning accuracy are at the same level of that of errors arising from image coordinate measurements. However, calibration accuracy for the rotation parameter ω and κ is not stringent.

Accuracy for time referencing is also important but is technically achievable. The tests showed that if the error of 10^{-3} second in synchronization can be controlled, the resulting position error is less than 4 cm at a vehicle speed of 60 km per hour (Schwarz and El-Sheimy, 1996).

3.3.3 Accuracy Improvement

The accuracy from an individual sensor component is discussed above. However, effective combination of these sensors and integrated processing of the sensory data will be able to further improve the total system accuracy. There are basically two levels of the integrated processing: (1) integrated processing of multiple positioning sensory data; and (2) integrated processing of positioning and mapping sensory data. For example, if GPS and INS are combined for positioning, the INS drifts with time can be largely controlled by using GPS updates while GPS outages and cycle slips can be corrected by using INS data (Wei and Schwarz, 1990; Schwarz and Wei, 1994; Toth and Grejner-Brzezinska, 1998; and El-Sheimy et al., 1999). As for the second level of integrated processing, image-based sequential triangulation using the tie points from the overlapped images can be used to determine the orientation parameters of each image. This technique can be used to augment the georeferencing accuracy derived from the positioning sensors or to bridge gaps where the GPS signals are lost. However, this technique is not as effective as that being used in the airborne photogrammetry. This is mainly due to the poor triangulation geometry of tie points obtained from the terrestrial images. The accuracy evaluation and the automatic determination of these tie points can be found in Bruce and Chapman (1998). One good example on the use of this technique for georeferenciens of terrestrial digital images can be found in Silva et al. (2000).

3.4 The VISAT™ Mobile Mapping System

The VISAT™ system was developed by The University of Calgary in cooperation with Geofit, Inc., Canada. The project began in November 1992, and the first demonstration was given in July, 1993. The production system was implemented in 1995. The VISAT™ has evolved from a 3-camera system to a 5-camera system, and is currently an 8-camera system. The overall objective of the VISAT™ project was to develop a precise mobile mapping system for road inventory and general GIS data acquisition, which is capable of providing an absolute positioning accuracy of 0.3 m and a relative accuracy of 0.1 m for object points within a 30 m corridor, at vehicle speeds of 50-60 km per hour (Schwarz et al, 1993).

The van-based VISAT™ system is shown in Figure 2. This system consists of a strapdown INS system, two L1/L2 GPS receivers, eight black/white CCD video cameras, an Antilock-Braking System (ABS), an image control unit, and a color S-VHS camera. The function of each component can be subdivided into primary and secondary functions (Schwarz and El-Sheimy, 1996). In terms of primary functions, the cameras provide 3D positioning with respect to the VISAT™ vehicle reference, which in most cases is the perspective center of one of the cameras. The position of this reference with respect to the existing control is determined by differential GPS techniques, while the camera attitude information is given by the INS. The ABS system will trigger the camera at constant distance intervals using the VISAT™ controller trigger channel. In terms of secondary functions, the cameras provide redundant image information of the objects, i.e., more than two images of the same object are available. The GPS is used to control INS drift errors, while the INS is used to bridge GPS outages, correct GPS cycle slips, and perform precise interpolation between GPS fixes. The ABS data can be used to update the INS data in case of the GPS signal blockage.

The road-related spatial data can be acquired through the on-line synchronization of GPS, INS, ABS, and image data. The georeferencing parameters of the moving VISAT™ reference system can then be obtained after processing the DGPS/INS inputs. Locations of objects of interest in the road corridor with respect to the VISAT™ reference system are determined during the post-mission processing, using two or more georeferenced images. The information extracted can be directly used to update or generate GIS databases.

The imaging component of the VISAT™ consists of eight COHU 4980 video cameras, each with a resolution of 640 x 480 pixels. The technical specifications of the camera are given in Table 4. The cameras are housed in a pressurized case and mounted inside two fixed-base towers on top of the van. Practical tests of the achievable system accuracy can be found in El-Sheimy (1996), and Schwarz and El-Sheimy (1996).

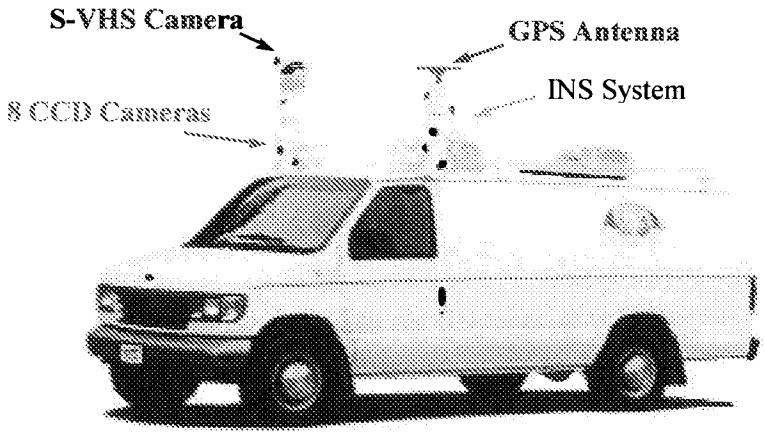


Figure 2 The VISAT™ mobile mapping system

Table 4. Technical specifications of the VISAT cameras

Parameters	**Specifications**(RS 170 standard)
Image area	6.4 x 4.8 mm
Imager type	IT CCD with on-chip microlenses
Cell Size	8.4 x 9.8 micrometers
Resolution	768 x 494 pixels
Field of view	43° (H) and 37° (V)
Electronic shutter	Eight options: 1/50 ~ 1/10 000 second

4 Information Extraction and Management

The major efforts of research and development have been placed on the improvement of quality and reliability of image georeferencing. Although automated information extraction from collected images is of considerable importance, few work has been done in this area. The Ohio State University (OSU), U.S.A., and The University of Calgary (UC), Canada, are most active in this area (Tao et al., 1999). Nevertheless, the related techniques of automatic information extraction from image sequences have been extensively researched, especially in the areas of mobile robotics, autonomous vehicle navigation and intelligent transportation systems.

Information management of large amount of images, mainly, raster data, as well as extracted vector data have been dealt by many GIS researchers and IT (Information Technology) practitioners. Information management has advanced to a point that vast amounts of image data can be handled, archived and retrieved effectively by using the spatially enabled relational database technology. At present, however, feature extraction is mainly manual. This labor-intensive process remains fairly costly in mobile mapping production and, therefore, prevents the wide acceptance of mobile mapping as a primary mapping tool. In the following, the current research status of automated information extraction is reported.

4.1 Object Measurement

The objects of interest can be footprints of houses, street edges, centerlines, curbs, lane markers, manholes, culverts, fire hydrants, traffic signs, telephone booths, electric poles, etc. In order to calculate the 3-D coordinates of an object from images, at least two conjugate image points need to

be determined. Since the orientation parameters of the cameras are known, the corresponding epipolar lines in a stereo image pair can be computed. Once a point in the left image is measured manually, the corresponding point in the right image can be determined by using the epipolar-line based image matching method. The area-based cross-correlation matching was used in the OSU group for the automatic determination of image conjugate points (He and Novak, 1993).

Further improvement of the 3-D coordinate accuracy of object measurement was researched by Li et al. (1996) and Tao et al. (1997). Their work focused on the use of multiple images to perform photogrammetric triangulation. Their results demonstrated that the final 3-D coordinate accuracy can be improved if multiple corresponding points in image sequences can be used. It is required that multiple corresponding point be established first. In fact, use of multiple images is valuable not only for enhancing the reliability of image matching, but also for increasing the 3-D coordinate accuracy of photogrammetric triangulation. A semi-automatic multiple-image-based object measurement method was developed by Tao et al (1997).

4.2 Road Centerline Reconstruction

Road centerline information has been extensively used to generate road network information systems. Such information can also be used to derive road inspection parameters such as the longitudinal profile and surface deformation, which are important indicators for road maintenance. The acquisition of up-to-date road centerline data using conventional field survey is fairly difficult due to the cost and logistical reasons.

Since the image features of road centerlines are relatively distinctive, it is expected that automatic reconstruction of road centerlines from mobile mapping images can be realized. The first trial was conducted by He and Novak (1992). After the manual input of a starting point of a centerline in image, the line following algorithm was executed to trace this centerline. However, this method can not handle the difficult road scenarios and does not have the capability of continuous reconstruction of road centerlines from a long image sequence.

A fairly successful approach to automatic centerline reconstruction was developed by Tao (1996) and Tao et al. (1998). This approach is based on a new theory "shape from image sequences". In this approach, the GPS/INS trajectory is used as an approximate 3-D road centerline shape model. This model is then gradually refined and updated by using road feature points extracted from image sequences. Constraints-based feature extraction and sophisticated multiple image matching techniques were integrated into this approach. It has been tested extensively that the approach functions very reliably even under poor imaging and road conditions. Another great advantage of the approach is that continuous 3-D reconstruction of road centerlines from entire image sequences can be realized.

4.3 Object Detection and Recognition

Without use of sufficient knowledge or image constraints about objects, results of automatic object recognition can never be reliable. Although there is an extensive literature covering the traffic sign detection and recognition, many problems remain unsolved. He and Novak (1993) published their results on the detection of mile makers from mobile mapping images. The focus was placed on the recognition of numbers appearing on mile-maker images. Geiselmann and Hahn (1994) developed a method of identification and location of stop signs. Firstly, mathematical morphology-based operations were applied to detect the region of interest. Then affine-invariant features were extracted to identify the simple shapes of objects. Many object recognition methods employed the color segmentation approach (Janssen et al, 1993; Priese et al., 1994; Tong et al., 1999). However, the segmentation results may be subjected to the conditions of lighting, shadows, weather, and sign painting, etc. The robustness of these approaches is still a major concern.

Semi-automatic object detection scheme presents an alternative due to the complexity of automatic object recognition. The basic principal of this scheme is that the human operator plays a role for object recognition. After an object is recognized by a human operator, automatic detection and

precise location of objects are then conducted by the system (Tao and Lin, 1994). Tao (1999b) has developed an approach to extract and locate vertical line features from mobile image sequences. In this approach, a map database was used to predict the approximate location of the object. Then a set of algorithms, such as line grouping, feature correspondence and line reconstruction was used to detect the presence of the object and locate precisely the object from the image.

Except for the above mentioned work, there are some of interesting research addressing the generic road extraction from image sequences. In fact, automatic road extraction was a main topic for robot navigation and autonomous vehicle navigation. Interesting readers may refer to the literature (Waxman et al., 1987; Turk et al., 1988; Ma et al., 1999; Habib, 2000). Automatic road width measurement has been investigated in Gajdamowicz (1999).

5 Applications of Mobile Mapping Systems

Mobile mapping is an innovative concept. With a mapping system installed on a mobile platform, e.g., van or helicopter, many of costly field surveys can be replaced. Its potential applications appear to be limitless. Typical applications include:

Mapping of roads and railways for asset management and engineering planning

Mapping of roads and railways is perhaps the main application market. Mobile mapping systems can delivery maps of road features at the sub-meter accuracy. Such maps can be used for transportation departments for road assessment management, transportation planning and engineering. Engineers are then able to access road images and attributes for any engineering purposes without going to the field. The typical end products out of a mobile mapping project are:

a) captured digital images of roads and pavements
b) road centerline maps derived from stereo images
c) positions of visible objects, such as traffic signs, manholes, guardrails, bridges, culverts, utility poles, buildings, trees, and road crossings, etc.
d) road related feature information, such as mile marker positions, distance attributes, road segments, and road attributes

Utility mapping and inventory

These maps are mainly used by utility and telecommunication companies. The accuracy may not be as strict as land surveying maps. However, it requires more frequent updating. Utility features such as transformers, power lines, telephone lines, street light poles, are need to be geocoded and linked to a road centerline based map database. Normally, the heights or the offsets of utility poles and cable attachments need to be measured. This information helps companies for design, planning and maintaining of electric unities, phone or cable routing.

Infrastructure mapping for emerging responses

Due to the wide implementation of E-911 services for emerging responses in North America. Positions and attributes of buildings, important landmarks, telephone booths etc. are required for the establishment of emergence response databases. It helps decision makers to layout the response routing and dispatch emergency vehicles. The images collected can be used to assist the appraisal, evaluate the condition and prepare for any special treatment.

It is worth mentioning that ITS presents a huge potential market for mobile mapping applications. It is projected that $209 billion will be invested in ITS between now and the year 2011 in the form of consumer products and services. The full-scale deployment of mobile mapping technology will take place for ITS data acquisition, database updating and information management.

6 Concluding Remarks

Mobile mapping represents a significant advance in multi-sensor integrated digital mapping. It provides a new avenue towards rapid and cost-effective collection of high-quality road related

spatial information. It is a truly multi-disciplinary endeavor that involves navigation and positioning, photogrammetry, geodesy, digital imaging and Geospatial Information Systems.

The fast commercialization transfer of the technology to the market indicates its industrial demand. The systems initially developed by the University of Calgary, Canada, and by the Ohio State University, USA, have been both commercialized.

However, it is a fact that current mobile mapping systems have not gained widespread acceptance in the mapping and surveying community. This is mainly due to its technical complexity and the associated high development costs. The initial investment for such a system is considered too high for most survey and mapping firms, especially if the system is not operated daily. The other reason is that many ground objects can not be captured by the vehicle-based mobile mapping systems, for example, building footprints and parcels that are important elements for surveying and mapping.

The author believes that mobile mapping will demonstrate its power in much wider application areas, particularly in ITS related applications, that is beyond the conventional surveying market. With the continuous advancement of mobile mapping technology as well as the reduced costs of the system development, mobile mapping potential will be explored further.

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LESSON 4
MOBILE MAPPING SYSTEMS

Introduction

A more recent development has emerged in spatial data collection - mobile mapping systems (MMS). It is relatively new in the sense that the first operational system was established in the early 1990s at the Center for Mapping at the Ohio State University with the development of the GPSVan™. Soon after this development, research was undertaken at the University of Calgary in this same arena with the development of the VISAT (Video, Inertial, and SATellite GPS) van[1]. The idea was to provide an accurate and economical means of collecting spatial data. Conventional methods were too expensive and time consuming.

A mobile mapping system can be defined as "a moving platform, upon which multiple sensor/measurement systems have been integrated to provide three-dimensional near-continuous positioning of both the platform and simultaneously collected geo-spatial data, with no or limited ground control using single or multiple GPS base stations" [Grejner-Brzezinska, 2002]. It involves the integration and management of different data collection devices along with data processing and management software to provide the user with the location of spatial features that exist on the earth. Three basic measurement components comprise most MMS: global positioning system (GPS), inertial measurement unit (IMU) or other form of dead-reckoning sensor, and an image capture system. Thus, a mobile mapping system that utilizes multiple sensors is "the product of integrating the concepts of kinematic geodesy and digital photogrammetry, to acquire, store, and process, measurable quantities that sufficiently describe spatial and/or physical characteristics of a part of the Earth's surface" [Mostafa and Schwarz, 2001].

While a MMS is often associated with data capture strategies using vans, in reality it involves any scenario where the sensors are in motion. This includes, in part, vans, airplanes, satellites and humans walking from place to place. Lidar (Light Detection And Ranging), or laser altimetry, is an example mobile mapping system where the image capture involves range measurements instead of conventional imagery. This technology will be discussed separately. Other image capture techniques, such as hyperspectral, promise to expand the applications of mobile systems.

Land vehicle navigation has been around for some time. Numerous developments have occurred in

- Automatic Vehicle Location and Navigation (AVLN)
- Intelligent Vehicle Highway Systems (IVHS)
- Intelligent Transportation Systems (ITS)
- Mobile Mapping Systems (MMS)

[1] The VISAT mobile mapping system is a joint endeavor between the University of Calgary and VISAT Technologies, Inc.

SYSTEM	CHARACTERISTICS	APPLICATIONS
Autonomous	Stand-alone vehicles with positioning devices and a map database	Used in personal vehicles for on-line guidance and assistance; basically replacing paper maps and yellow pages
Fleet Management	• Fleets of vehicles linked to a control center via communications link. • Although positioning sensors are available in the vehicles, the map databases are not necessary. • The control center is responsible for the transmission of the necessary information to the vehicle on call	Civic applications, such as police, fire fleets, ambulance, delivery services
Advisory	• A blend of autonomous and fleet management architecture. • Not controlled by a dispatcher center, but part of a fleet that is being served by a traffic control center. • The control center is a mobile service center • Vehicles receive updated information regarding traffic and weather information without the control center being able to identify them.	• Used for access to route information, such as real-time traffic information, turn restrictions, one-way streets, and, in some systems, weather conditions. • Essential to minimize route travel time and to prevent and avoid traffic congestion.
Inventory and Mapping	• Autonomous vehicles equipped with navigation and imaging sensors. • May have a communications link with a control center	Used in the inventory of road conditions, mapping, and general GIS applications.
Portable	Autonomous systems that are not permanently installed in a vehicle	Used by tourists, hikers, real estate agents, hunters, business travelers, and others.

Table 1. AVLN Systems, Characteristics and Applications [from El-Sheimy, 1996].

AVLN systems are classified into 5 different types [El-Sheimy, 1996]: autonomous, fleet management, advising, inventory and mapping, and portable. The characteristics and applications are shown in table 1. In early AVLN systems, a single sensor was used for navigation purposes. These included GPS, land-radio-station techniques like LORAN C, road-facility infrastructure such as beacons, or dead-reckoning (DR) systems like a compass and odometer. But, they all have weaknesses when used singularly. Therefore developments into integrated systems were undertaken to provide better performance, more

versatility, increased accuracy, and improved reliability. The significant drawback is the high cost associated with integrated systems [El-Sheimy, 1996].

With the technological developments that have occurred in these three areas, along with the enhancements in computers and computer processing, MMS has undergone significant changes during the decade that it has been utilized in production. For example in the first generation of the GPSVan™, wheel sensors (odometers) and gyros were used to determine heading, attitude, and distance. Today, these systems have been updated with IMU. Moreover, digital camera systems that were crude by today's standards have been upgraded to reflect the developments in this area as well.

Why is mobile mapping important since we already have numerous tools that allow us to capture data efficiently? As we will see, by integrating different sensors into a complete system we can optimize the data collection. Many of the sensors are complementary tools that provide useful, and sometimes redundant, information. The sensors found in many mobile mapping systems utilize different physical principles that help the user determine object properties in different forms. The result should be better interpretation of the scene [Grejner-Brzezinska, 2001a].

Mobile Mapping Systems

The VISAT van is designed to achieve high accuracy survey data collection in an operational environment with speeds up to 60 km/hr. The system is comprised of a Honeywell Laser-Ref III strapdown inertial measurement system, two Ashteck Z12 GPS receivers, a cluster of 8 video cameras, an anti-braking-system (ABS) pick-up, a Super Video Home System (SVHS), and an image control unit. El-Sheimy and Schwarz [1998-99] identify the primary and secondary functions of the components in table 2.

Sensor	Primary Function	Secondary Function
GPS	Provides the camera position in 3D space	• Controls the INS error propagation • Provides system synchronization • Gives coordinates in WGS 84
INS	Provides the camera orientation in 3D space	• Bridges GPS outages • Corrects GPS cycle slips • Gives precise interpolation between GPS fixes
Cameras	Two georeferenced cameras provide the position of objects in 3D space	• Provide redundancy, i.e., more than 2 cameras/images of the same object • Can be used to update navigation data through triangulation procedure
ABS	Triggers the cameras at constant distance intervals	Updates the INS data if the GPS signal is blocked for periods longer than the INS bridging level required to fix GPS ambiguities (half a cycle)

Table 2. Primary and secondary functions of VISAT system components [from El-Sheimy and Schwarz, 1998-99, p.276].

Not all MMS utilize the same number or types of sensors. For example, Lambda Tech[2] operates the GPSVision™, which utilizes a Trimble 7400 dual frequency GPS receiver, a Litton LN-200 INS, and two progressive CCD cameras (one color and one black/white). Figure 1 shows the GPSVision™ MMS. Grejner-Brzezinska [2001a] presents a list of different mobile mapping systems available at that time. These are shown in table 3.



Figure 1. GPSVisionTM mobile mapping system.

As we can see, a multitude of sensors can be utilized in a particular MMS. As an overview, the functions of these different sensors are shown in table 4 [Grejner-Brzezinska, 2001a].

Mobile Mapping Concepts

Advanced mobile mapping system consists of four basic parts within an operational environment. Three instruments are required, namely an imaging component, a georeferencing component, and a photogrammetric measurement component. They are brought together through a calibration component. These are described as [Grejner-Brzezinska, 2001a]:

- System calibration, which is performed after the system is completely assembled, consisting of

[2] See www.lambdatech.com/gpstech.html

MMS	Developer	Navigation Sensors	Mapping Sensors
GPSVan™	Center for Mapping, Ohio State University	• GPS/gyro/wheel counter • GPS/INS (second generation of system	2 CCD, voice recorder
VISAT	University of Calgary	GPS/INS/ABS	8 b/w CCD and 1 color SVHS
GeoVan	Geospan Corp., USA	GPS/DR	10 VHS, voice recorder
GPSVision™	Lambda Tech, Inc., USA	GPS/INS	2 color CCD
KISS	University of Bundeswher Munich and GeoDigital, Germany	GPS/IMU/Inclination Odometer/Barometer	1 SVHS, 2 b/w CCD, voice recorder
ON-SIGHT	Transmap Corp., USA	GPS/INS	4 color CCD
RGIAS	Rowe Surveying & Engineering, Inc., USA	GPS	Video, laser range finder
TruckMap	John E. Chance, Inc., USA	GPS/gyro/WADGPS	Laser range finder, 1 video camera
WUMMS	Wuhan University, China	GPS	3 video cameras, laser range finder
ROMDAS	Highway and Traffic Consultants, Ltd., New Zealand	GPS	Digital video camera
DDTI	Digital Data Technologies, Inc., USA	GPS	Touch-screen, voice recorder
POS/LV™ 420	Applanix Corp., Canada	GPS/INS/distance measuring instrument (DMI)/GPS azimuth measurement subsystem (GAMS)	CCD, video

Table 3. Description of different mobile mapping systems.

Sensor	Functionality
GPS	• Image geoprocessing in 3D • Time synchronization between GPS and INS • Image time tagging • INS error control • Access to the 3D mapping frame through WGS84
INS	• Image orientation in 3D • Supports image georeferencing by: ○ Bridging GPS gaps, and ○ Providing continuous (256 Hz) trajectories between GPS measurement epochs • Supports ambiguity resolution after losses of lock, and cycle slip detection and fixing
Camera	• Collects imagery used to derive object position ○ Two (or more) cameras provide 3D coordinates in space ○ Single camera provides 2D coordinates or 3D if overlapping images are used
Laser Range Finder	• Supports feature extraction from the imagery by providing precise distance (typically measuring accuracy is about 2-5 mm)
Voice Recording, Touch Screens, Barometer, Gravity Gauge	• Attribute collection sensor

Table 4. MMS sensors and their functionality.

  - GPS/INS lever arm – this is the distance between the phase center of the GPS antenna and the center of the INS body frame.
  - Camera calibration.
  - INS/camera boresight calibration, which is the distance offset and angular relationship of the INS and camera to the body frame.
- GPS/INS/image data collection, which comprises
  - GPS/INS/camera time synchronization.
  - Data logging.
  - Image compression and storage
- GPS/INS post processing involving the georeferencing of the time tagged images by computing the six exterior orientation parameters
- Image processing of the images to determine the location of the georeferenced features of interest within the imagery.

The "brain" within a MMS is the onboard PC. It is used to integrate and support the different measurement systems. The computer will take the data measurements and store it for later processing. Finally, it can be used to facilitate the interaction between the MMS and the system operator during the data collection phase [Grejner-Brzezinska, 2001b].

Navigation

The navigation component consists of two basic systems: GPS and the IMU. The primary function of the GPS receiver is to provide position information for the imaging sensor at the instant of measurement (exposure), although it is also possible to use the GPS for platform orientation. In addition, it can also be used to control errors that accumulate within the IMU. The GPS receivers are used in a differential mode with one receiver[3] located on the vehicle and one receiver set up over a known control point in the survey area. For a more robust solution, two base stations can be occupied simultaneously with GPS. This will yield two positions for the GPS roving receiver and helps in quality control of the MMS. Carrier phase is generally measured because it provides a much higher accuracy than pseudorange measurements.

From the GPS carrier phase, ranges from the satellite to the receiver along with their range rates are output from the receiver. These measurements yield position and velocity values for the vehicle with respect to the initial point. Using differencing techniques, the orientation of the system can also be determined. The disadvantages of GPS include [El-Sheimy, 1996]:

- Possibility of cycle slips

[3] It is possible to use multiple GPS receivers on the vehicle to determine the orientation of the platform and also to provide redundancy/backup to the primary GPS receiver.

- The range and range rates are not truly independent
- The accuracy at the GPS sample rate cannot meet the accuracy requirements for orientation of the system.

As we are all aware, the global positioning system provides us with very accurate positioning data over the entire surveying mission. Unfortunately, GPS does not work properly in all environments. GPS measurements are susceptible to poor satellite geometry, cycle slips, satellite outages, and a dynamic lag that may occur during vehicle maneuvers. Situations where such conditions can occur can be found in urban centers (the so called urban canyon) and along highways where overpasses and tunnels obstruct the satellite signals.

Moreover, within a MMS, the relationship between the phase center of the antenna needs to be known relative to other sensors. But, the phase center is not a physically identifiable point, nor is it stable in time or space [Greening et al, 2000]. The effect is generally dependant on the elevation of the satellite and varies as the satellite signal direction changes. There is also a problem when the variation of this phase center movement is superimposed on the GPS data for determination of tropospheric scale factor. Errors in the range of 10 cm have been found in the vertical component.

Greening et al [2000] also draw upon personal experiences with problems involving solving for integer ambiguities. Over the years, they have found situations where it appears that the integer ambiguities have been solved but in reality may be incorrect, which could introduce errors up to the 30 cm level. Generally this affects the vertical component more. For accurate (centimeter level) results, the integer ambiguities must be known for all satellites and maintained, or quickly resolve, during the photo mission. Comparison of forward and reverse processing of GPS can be used to find this problem but this does not always work. The problem with the integer ambiguity is exacerbated by other environmental conditions such as sudden PDOP changes that could occur in aircraft banking operations, multipath, baseline distances, radio frequency (RF) interference, and phase center variations. From experience and under reasonably good conditions, "the positional accuracy (1σ) relative to the ground station(s) may vary from 5 to 30 cm, in any component (X, Y, Z), even during a single mission completed in a short time period" [Greening et al, 2000].

The second element of the navigation component is the inertial navigation system (INS), which accurately measures linear acceleration and angular rates. One of the advantages of the IMU is that it is a self-contained system that does not rely on external sensors, such as the necessity to capture satellite data as in GPS. Its primary function is to obtain the orientation of the camera at the exposure. Additionally, when used in the positioning mode, it can also be used for bridging between GPS outages, to correct for cycle slips, and to provide precise interpolation between GPS epochs [El-Sheimy, 1996]. Over a short period, INS positions and navigation results are extremely accurate. Unfortunately, over time the errors will tend to accumulate.

There are two different types of inertial navigation systems. In the gimbal system the inertial unit is always moving whereas in a strapdown system the inertial unit is fixed to the vehicle. Conceptually, the use of a strapdown inertial measuring unit (IMU) is very simple. The instrument consists of 3 gyroscopes that are used to measure angular motion and 3 accelerometers, which measure forces in 3 different orthogonal axes in the inertial or fixed non-rotating frame. The IMU is based on Newton's law of motion given as [Grejner-Brzezinska, 2001b]:

$$\bar{\ddot{r}} = \bar{a} + \bar{g}$$

where $\bar{\ddot{r}}$ is the vector of the total inertial acceleration, $\bar{a}$ is the applied force vector, and $\bar{g}$ is the vector describing the total gravitational acceleration. While the IMU does not measure the gravitational field, it is affected by the forces due to gravity. Therefore, for navigational purposes, gravity information must be provided to the system processor.

An inertial survey begins with an initial alignment to determine the initial position, velocity and attitude of the platform. The angular velocity can be integrated in time thereby yielding the vehicle's change in orientation measured with respect to the initial orientation. In other words, the vehicle's attitude and velocity are known. The forces are used in a double integration with respect to time giving the difference in position from the initial point. Due to the double integration, the position is time dependent and the errors will quickly accumulate [El-Sheimy, 1996].

To control errors within the IMU, the system needs to be regularly updated. Errors in the inertial navigation system stem from the initial sensor misorientation, accelerometer biases and gyro-drift [Grejner-Brzezinska, 2001b]. In the past this has meant stopping the vehicle so that the IMU comes to rest again. This is referred to as a ZUPT (Zero Velocity Update). There are several disadvantages to using a ZUPT in MMS [El-Sheimy, 1996]:

- Limits the system to semi-kinematic applications
- It is not possible to safely stop the vehicle on highways or on high-traffic roads without interrupting the flow of traffic
- Stopping the vehicle reduces productivity, which negates one of the advantages of a MMS.

Nonetheless, zero velocity updates are important for significantly controlling INS error accumulation where prolonged and/or frequent loss of GPS signals exist. In advanced systems the integrated GPS/INS system can be programmed to tell the operator when a ZUPT is required. This is done by monitoring the PDOP from the GPS satellite constellation and the duration of the GPS outage/blockage. Knowing that the error grows with time, the system can predict when a ZUPT is required. Some systems will also activate a ZUPT when the vehicle stops with the normal traffic flow.

How frequently should a ZUPT be performed? Most obviously, it is required before the INS error accumulation gets too large. Grejner-Brzezinska and Toth [2003] indicate that for prolonged GPS blockages, a ZUPT should be performed every 1-2 minutes during the

blockage. For example, they show the effects of a free navigation on the accuracy with and without a ZUPT. This is shown in table 5. In the first row, the free navigation was performed for 140 seconds with no ZUPT. The resulting errors were 0.16, 0.45 and 0.16 m for easting, northing and height coordinates respectively. Line 2 shows the effects when using a 20 second ZUPT during the same 140 second interval (60 seconds free navigation, 20 seconds ZUPT, and 60 seconds free navigation). The results in the northing and easting are reduced significantly, while the height component is only marginally improved.

Free Navigation (seconds)	ZUPT (seconds)	Free Navigation (seconds)	Total Error (meters)		
			East	North	Height
60	0	80	0.16	0.45	0.16
60	20	60	0.03	0.02	0.11

Table 5. Effects of ZUPT on the accuracy of the position [from Grejner-Brzezinska and Toth, 2003].

The reason for the ZUPT calibration is to control the INS errors such that when reacquisition of the satellite signal occurs that the integer ambiguities can be quickly and correctly resolved. Again, Grejner-Brzezinska and Toth indicate that the longer the blockage the more the need for a ZUPT. With no ZUPT for large gaps before reacquisition then the number of ambiguities that will be resolved is significantly lower. The duration of the ZUPT appeared to have little effect. Therefore a ZUPT for 10-20 seconds is sufficient for ZUPT calibration.

Integrating GPS with the IMU offers an alternative to IMU error control. In fact, Cramer [1999] states that in the highly dynamic mobile mapping environment the GPS is the best instrument to integrate with the IMU in order to meet the accuracy needs of the mapping.

Working together, the GPS and INS form complementary position and navigation systems. The GPS is used to reduce the long-wavelength errors that are present within the inertial system. Moreover, when the GPS receiver loses lock on the satellites, the INS can help reinitialize the GPS once lock has been reacquired. Finally, GPS has a relatively low data sampling rate, normally 1 Hz, while the INS produces attitude and position up to 100 Hz.

How is the positioning done with an integrated GPS/INS sensor configuration? The key is a Kalman filter. The system is comprised of a state vector consisting of attitude, position, velocity, accelerometer biases, and gyrodrifts. The filter is used to predict values for the state vector. As new measurements are made, the Kalman filter uses those measurements to predict a more accurate state vector. Since a Kalman filter is a mathematical model used to modify the state vector, any different types of filters exist. Cramer [1999] states that a 15-state model may be acceptable for most cases. This filter may contain 9 navigation-error terms that describe the position, velocity and attitude errors and 6 sensor-error terms that describe the performance of the specific IMU such as gyro drift

and accelerometer bias. Other error terms could also be added to this basic model. It can be shown schematically in figure 2.

Kalman filters can be either centralized or decentralized. In the centralized scenario, both GPS and INS errors are modeled. Reference trajectory is determined through the INS data measurements while the GPS data are used to update the solution. A decentralized Kalman filter utilizes two filters running continuously with only occasional interaction to each other. The GPS data passed through its Kalman filter is used to determine position and velocity data which are then used to update the INS Kalman Filter [El-Sheimy, 1996].

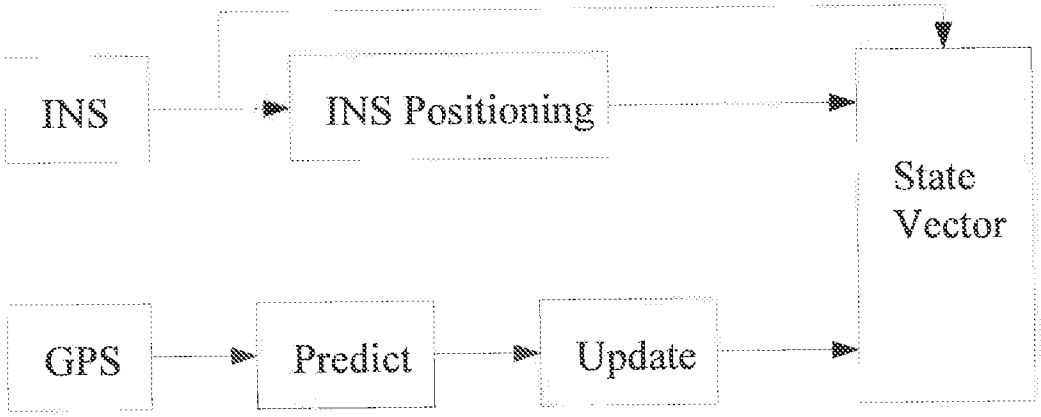


Figure 2. GPS/INS integration procedure (from www.lambdatech.com/gpsv-3.html).

Direct Sensor Orientation

As it can be surmised from the earlier discussions, the integration of GPS and IMU can be used to orient the sensor in a process referred to as direct sensor orientation (DSO)[4]. The potential advantage of DSO is that it can eliminate the need to perform aerotriangulation. The significance is that historically, aerotriangulation (AT) has been used to aid the photogrammetrist in their mapping projects. As a byproduct of the AT process, the exterior orientation parameters are determined. As Cramer states, "determination of the exterior orientation parameters is an essential pre-requisite for the geometric evaluation of any kind of imagery from terrestrial, airborne or satellite based sensors" [Cramer, 1999, p.59].

There are several advantages of DSO with respect to aerotriangulation [Cramer, 1999]:

[4] Direct sensor orientation is also referred to as direct platform orientation, direct georeferencing, direct geocoding, and even direct EO (for direct exterior orientation).

- The exterior orientation can be acquired faster within a combined GPS/IMU than conventional aerotriangulation, including automatic AT with digital imagery.
- There is more flexibility in image acquisition since AT, even with airborne GPS, requires flights to be collected in well-known block functions which may be a disadvantage for small-areas or linear projects.
- While automatic AT has continued to mature, it requires a significant computational burden that becomes even more difficult, and sometimes impossible, when the matching is performed over areas of steep slope, no texture, forested and water areas, and large urban areas.

Quality Control

A critical element in the positioning of the vehicle is the quality control (QC) component. The VISAT system handles QC in two different ways. First, it has incorporated a real-time alert system that signals the user when the system performance will not meet the expected accuracy of the survey. The second part is post-mission processing of the data. This consists of a series of programs that correct for cycle slips within the GPS measurements, performs INS bridging, and undertakes backwards smoothing. The modules are employed to correct for a loss of the GPS signal. While post-processing can be used to correct for some problems encountered in the survey, real-time QC is necessary in order to ensure that sufficient INS and GPS data have been collected to help process the vehicle trajectory to the specified accuracy [El-Sheimy and Schwarz, 1998-99].

Poor satellite geometry is usually not a major issue provided that it only increases the GPS white noise. Using the numbers derived from the dilution of precision (DOP), an alert can be activated to warn of poor geometry. Proper INS integration with GPS and proper weighting of the observations will generally solve the geometry problem. But, poor geometry could introduce correlated position errors. When this happens, additional regular ZUPTs will be required in addition to the GPS data [El-Sheimy and Schwarz, 1998-99].

Another problem is cycle slips. When measuring phase with GPS, we can very precisely measure phase change, or the fractional part of the GPS signal, at the receiver. Unfortunately, it is not that easy to know the full integer number of wavelengths that existed between the satellite and the receiver. This is referred to as the integer ambiguity. There are methods that can be used to resolve this problem. A cycle slip occurs when we lose this integer value, usually because of a loss of lock to the satellite.

The existence of a cycle slip can be found by predicting the GPS double differences, $\nabla\Delta\varphi_{Predicted}$, with the inertial system coordinates. Then the cycle slip difference, v, is found by comparing the triple differences between the predicted and measured values [El-Sheimy and Schwarz, 1998-99].

$$v(t) = \nabla\Delta\varphi_{Predicted} - \nabla\Delta\varphi_{Measured}$$

where

$$\delta\nabla\Delta\varphi_{Predicted} = \nabla\Delta\rho(t)/\lambda$$

and: t = the current epoch,
$\nabla\Delta\rho$ = the double-difference range from the INS predicted coordinates,
$\nabla\Delta\varphi$ = the GPS double-difference values, and
λ = the wavelength of the carrier phase.

A simple approach to fix the cycle slip in real-time is to find the absolute value of $\nu(t)$ and compare it to some threshold value. This threshold criterion must be under a full cycle if centimeter accuracy is required. This will tell the user if any cycle slip has occurred since the last GPS epoch. If the value for the cycle slip difference exceeds the threshold then simply add the integer, as shown by

$$\nabla\Delta N_{New} = \nabla\Delta N_{Old} + INT(\nu)$$

where $\nabla\Delta N$ is the integer value of the full wavelength and INT is the 'nearest integer' function [El-Sheimy and Schwarz, 1998-99].

Another approach is to perform the cycle slip recovery by post processing. If real-time is not necessary, this method is better since one can use the double-differences directly without the time differential of the triple differences. This is done by modeling $\nu(t)$ as a function of the time through the epochs before and after the cycle slips thereby decreasing the noise. Moreover, it is not always necessary to correct for loss of lock and cycle slips in real-time [El-Sheimy and Schwarz, 1998-99].

INS bridging is generally used in post-processing. Its advantage is that it utilizes more INS information. INS bridging involves using the inertial system predicted coordinates for the position of the GPS receiver after it acquires the satellite signal. Provided that the INS errors are less than a half cycle, correct integer ambiguities can be determined. If the errors are larger than this, a constant bias will be introduced into the ambiguity. This can be eliminated using an on-the-fly (OTF) integer ambiguity procedure [El-Sheimy and Schwarz, 1998-99].

As an additional measure of quality control, independent ground control can be observed [Grejner-Brzezinska, 2001a]. The control can either be existing control in the survey area or new control established for an independent check.

Imaging Component

An important part of a MMS is the imaging system. The VISAT system consists of 8 digital cameras that are mounted in two towers. Each camera has a 640 x 480 pixel resolution. The two towers are placed on the top of the van with a fixed base between them. This is important because it will remain a constant throughout the survey. Six of the cameras are oriented to provide 230° of horizontal and 40° of vertical coverage. The other

two cameras are used for special types of surveys, such as powerlines, and have a different vertical field of view [El-Sheimy and Schwarz, 1998-99].

All cameras are synchronized, therefore when an exposure is made the eight images will all relate to the same vehicle position. The images are then compressed in real-time and stored to a RAID (redundant array of independent hard disks). This system stores up to 20 GB of data, which corresponds to about 150 km of survey data. GPS time is tagged to each image, which is used later in georeferencing [El-Sheimy and Schwarz, 1998-99].

The VISAT controller is an integrated part of the imaging system. Two input channels are available for the ABS data and the GPS receiver strobe output. The controller can perform the following functions [El-Sheimy and Schwarz, 1998-99]:

- Triggers the camera so that exposures are made at a set distance along the survey route,
- turn the cameras off/on when stopped at traffic lights,
- automatically time tag distance-dependent events using GPS, like the start/end of the ZUPT of the INS or start/end of GPS static periods,
- provide the synchronization pulse to ensure that all 8 cameras are exposed at the same time, and
- send an alert to the driver for ZUPT of the inertial system when frequent GPS signal blockages are encountered.

Timing Component

A critical part of high accuracy positioning when utilizing multiple sensors is timing. With three primary data collection instruments (GPS, INS and digital imaging system), georeferencing the image means that the relationship of the imaging sensor to the body frame as tied in by the GPS/INS system is time dependent. The system is brought together by time synchronization. Two of the instruments have timing boards, namely GPS and INS. GPS is an excellent reference frame. The INS also provides an accurate time reference but it usually operates in a free-run mode and seldom is it related to Coordinated Universal Time (UTC) [Grejner-Brzezinska, 2001a].

Generally in the MMS environment the INS clock is synchronized to the GPS clock during initialization. It can also be calibrated for clock drift, or scale error, in post processing. The timing board, which is synchronized to the GPS, is used to time tag the exposure of the image and the INS data records. Very high accuracy is possible. Grejner-Brzezinska [2001a] reports that calibration of the timing board can be done to about 0.2% with around 1ppm[5]. Response times range from 5-10 μs even for high event rates, such as 1,000 events/second. At a speed of 200 m/s, the timing error amounts to 1-2 mm of error.

[5] ppm is parts per million

Georeferencing concept

Georeferencing is the assignment of coordinates to feature points for a GIS. Historically, when imagery was used to locate features, ground control points (GCPs) were required. This led to indirect georeferencing since the location of the exposure station was determined by aerotriangulation using the basic concepts of resection of the GCPs. Determination of the control was an expensive phase that represented a large part of the cost budget for a project, depending on the particular site.

Photogrammetrists have been trying for years to improve the accuracy of the exterior orientation parameters and to reduce the number of GCPs needed for accurate mapping. While some successes were recognized, for the most part these auxiliary data measurements were abandoned for more robust aerotriangulation procedures. But with the advent of airborne GPS, things began to change. For the first time, photogrammetric projects could be undertaken with no ground control, although this was only true for block adjustment of overlapping imagery. Still, other sensors required GCPs. With the introduction of affordable and accurate INS, coupled with GPS, it is now possible to recover all of the six exterior orientation parameters, hence allowing the user to know the position and orientation of the sensor being used and in the data collection.

The geocoding component of a MMS consists of three parts: a calibration module, and position/altitude module, and a stereo module. The situation of a mobile mapping system is one that consists of three, and sometimes more, reference frames (see figure 3). The goal is to obtain the spatial location of features in real-world coordinates, whether they be in State Plane Coordinates, Universal Transverse Mercator (UTM) coordinates, geographic coordinates (latitude, longitude, and height), or some other earth-fixed framework. This referred to as the mapping frame (m-frame).

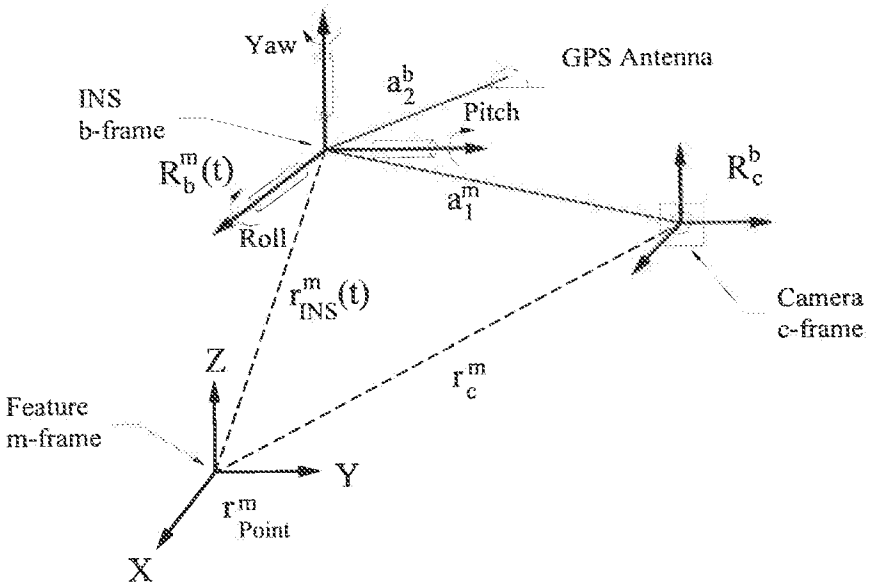


Figure 3. Georeferencing geometric relationships.

The vehicle itself also has its own reference frame, which is referred to as the body frame, or b-frame. When INS is employed, the b-frame is referenced to the inertial coordinate system. Finally, there is the reference frame of the sensor system. Since this frequently involves a camera, it can be called the camera frame or c-frame.

The process of georeferencing involves taking the imagery that is in two-dimensional space in the c-frame and transforming it to the m-plane. The c-frame is in a local coordinate framework tied to one of the cameras, often the left camera. The vector from the camera to the object, designated as r^c, is transformed to the vector from the origin of the earth-fixed coordinate system to the object, r_i^m. This is given mathematically as [El-Sheimy and Schwarz, 1998-99]:

$$r_i^m = r_{INS}^m(t) + R_b^m(t)\left(R_c^b \cdot s_i \cdot r^c + a^b\right)$$

where:

r_i^m = coordinate vector of point i in the m-frame,

$r_{INS}^m(t)$ = time-dependent vector defined between the origin of the mapping coordinate framework to the INS (or GPS) in the m-frame,

t = time of exposure,

$R_b^m(t)$ = time-dependent rotation matrix between the b-frame and the m-frame, which is measured by the INS,

R_c^b = rotation matrix (sometimes referred to as the boresight matrix) between the c-frame and the b-frame, which is defined in the INS coordinate frame,

s_i = scale factor applied to the photographic relating one camera to one point i,

r^c = coordinate vector in the c-frame, and

a^b = offset distance between the INS and the camera, which is commonly referred to as the boresight offset vector.

The relationship assumes that the IMU is rigidly attached to the body of the vehicle such that the body frame is defined by the INS sensor frame.

The rotation matrix, $R_b^m(t)$, between the b-frame and the m-frame is defined as [Grejner-Brzezinska, 2001b]:

$$R_b^m(t) = \begin{bmatrix} -\sin\lambda & -\sin\varphi\cos\lambda & \cos\varphi\cos\lambda \\ \cos\lambda & -\sin\varphi\sin\lambda & \cos\varphi\sin\lambda \\ 0 & \cos\varphi & \sin\varphi \end{bmatrix} R_{INS}(t)$$

where φ is the latitude, λ is the longitude and $R_{INS}(t)$ is the rotation matrix consisting of the heading, pitch and roll angles. This latter rotation matrix reflects the transformation

between the East, North and Up (ENU) coordinate system to an earth centered, earth-fixed coordinate system. If the mapping frame is expressed in a local coordinate system (ENU) then $R_b^m(t)$ is equivalent to $R_{INS}(t)$.

Photogrammetric Measurements

The digital cameras are synchronized to obtain the image at the same instant. Through the GPS/INS on-board the vehicle, these images are easily georeferenced. The cameras are used, together with photogrammetric theory, to obtain the 3-dimensional coordinates of the features in the object space. To do this, each object must be captured in at least two cameras from different vantage points. While it is possible to obtain the position from one image only, for high accuracy surveys, stereophotogrammetry is used. While conventional photogrammetry relies on the bundle adjustment to obtain the six elements of exterior orientation (the space location of the perspective center, X_L, Y_L, and Z_L, and the rotation angles, κ, φ, and ω), mobile mapping systems can obtain these values directly from the GPS/INS navigation information.

Once the images have been captured, the system is used to identify the features in the object space. Older systems utilized manual methods of identification of objects. Today, many of the systems can perform automatic, or nearly automatic, feature extraction. This is easily done using image processing techniques and has been very successful, especially for linear features and other features that have a recognizable geometric shape.

An example imaging system where near-real time automatic image processing is the second generation MMS developed by The Ohio State University (OSU) for the Ohio Department of Transportation (ODOT) for road centerline surveys [Grejner-Brzezinska and Toth, 2003]. This system consists of a downward looking, color digital camera. The advantage of this configuration is that the scale is nearly a constant from frame to frame. The predefined objects that are collected within the imagery are easily predictable. These objects include line marks, surface texture variations, cracks, potholes and skid marks. In tests conducted by Grejner-Brzezinska and Toth [2003] using post-processing techniques, two important factors came into play for real-time processing. First is the issue of data acquisition overhead. While the camera used in the MMS was capable of taking up to 30 frames per second, the dual Pentium 1.7 GHz used could only handle about 10 frames per second, requiring limiting the speed of the van to about 30 mph.

Second is performance of the image processing. They found a time dependency when performance is measured with respect to image quality and context. Using stereoscopic techniques, more processing time was required for images of poorer quality. Image processing would consist of determining image space coordinates and polyline extraction of centerlines. The object space coordinates would still be coarse requiring refinement using post-processing techniques.

Integrating instruments is not a new concept for photogrammetry. For example, merging flying height information to aid in the aerotriangulation is well documented in the literature of the 1970s. With the onset of GPS, enterprising photogrammetrists began to

mount receivers on-board the aircraft to capture the space position of the perspective center. Again, this data was used to aid in aerotriangulation. While the position of the camera was now observable, the orientation of the camera platform was not. It was through the development of inertial technology integrated with GPS that all of the six exterior orientation parameters were now available. This now gave the photogrammetrist the opportunity to perform direct platform orientation.

Another important development that aided MMS was the development of good quality and accurate digital cameras. Digital sensors are not new but how these sensors formed the image created problems from a photogrammetric point of view. For example, many of the early CCD sensors used in mapping consisted of a linear array. Here the image was formed line by line with each line being exposed at a different position. Therefore, a robust modeling of the sensor trajectory was required to create a geometrically correct scene.

Area CCD systems offered an approach that was more compatible to the principles used in photogrammetry and could be easily introduced into a working environment. Unfortunately, they are limited in size when compared to the 23-cm (9") square format usually used for photogrammetric mapping. For a typical aerial mapping project this would mean a smaller footprint thus requiring more exposures per flight line and more flight lines. For example, a 3" x 3" sensor requires the acquisition of 9 times more imagery, which adds time and increases data acquisition costs. This also increases the computational burden considerably since the number of point measurements would increase by one order of magnitude. But this can be made to be irrelevant when DSO is taken into consideration since this would decrease both processing time and costs. DSO plays an even more important role when linear sensors are used in the camera [Grejner-Brzezinska, 2001b]. Early projects for corridor mapping did show that digital imagery is a viable option for mapping. These smaller format cameras fit well into a corridor environment because the area of interest is usually smaller than typical mapping projects.

Despite the smaller format, digital cameras do offer some advantages over conventional analog film. For real-time applications, digital imagery is essential. With analog film, the film has to be developed and then scanned before it can be used in digital processing. Thus, digital imagery significantly reduces the turn-around time. Also, being in digital form, it can be directly inputted into a softcopy workstation for feature extraction processing. With DSO there is no need for aerotriangulation except for calibration and quality control purposes. Therefore, the additional imagery needed because of the small format becomes less of an issue. Additional advantages of a completely digital workflow are [Grejner-Brzezinska, 2001a]:

- improved triggering,
- low noise level,
- no signal corruption during storage, and
- no digitization needed for the imagery.

Digital imagery does require quite a bit of computer memory space. Fortunately, developments in data compression have almost negated this problem. In fact, Grejner-Brzezinska points out that it can compete very effectively when matched against film-based techniques. In a real-time environment, digital imagery can undertake a number of important tasks on the imagery. These are [Grejner-Brzezinska, 2001a; 2001b]:

- signal conditioning such as gain and offset control and color correction,
- image enhancements like real-time histogram collection and correction,
- imprinting, which is analogous to titling analog film, and
- image compression.

While these advantages are impressive, there are some issues that the user needs to recognize when one compares CCD arrays to analog film. These are [Grejner-Brzezinska, 2001a; 2001b]:

- It is impossible to manufacture a flawless array of CCDs. The bad pixel can, though, be identified and corrected for using image processing interpolation techniques. But, the potential exists for losing data.
- The read-out rate can be large, particularly in older systems. This is the time period required to pass the digital numbers within the pixel array to the storage medium and to "clear" the CCDs for the next image. This time may affect the flight planning in aerial missions. Newer systems have increased this rate, generally by using multiple output gates.
- Since the image is found in an array, it has a linear characteristic. Pixels may experience saturation or blooming. This an spill over to neighboring pixels.
- When compared to film speed (ASA), CCDs have a radiometric sensitivity in the 100-200 ASA range.
- The radiometric resolution of most scanned photographs produce a 6-7 bit intensity. CCDs, particularly cooled ones, can yield higher values, on the range of 10-12 bit resolution. This is due to the good signal-to-noise ratio.

Calibration

Like all measurement systems, calibration is crucial if we are to know precisely the accuracy of the measurement system. Since a mobile mapping system consists of three different and separate measurement systems, it is important to know how each behaves individually and, more importantly, how the system behaves during the measurement process.

Since MMS utilizes a direct sensor orientation, it is critical that a system calibration be performed. Generally, three different calibrations exist: internal geometry of the camera (camera calibration), offset between the GPS and INS (level arm calibration), and the offset between the camera and the INS (boresight calibration). This calibration should be performed to the highest accuracy possible since the subsequent measurements are all based

on these parameters. Additionally, the spatial relationships between the individual systems must remain constant throughout the mapping project [Grejner-Brzezinska, 2001b].

There are some important issues related to the calibration of the CCD cameras. Conventional aerial camera calibration used to evaluate conventional 23-cm format cameras cannot be used to calibrate digital cameras. There are some questions about the long-term stability of the camera parameters. Thus, calibration using self-calibration using different test fields in in-situ field procedures would appear to be the ideal method of deriving the camera parameters [Grejner-Brzezinska, 2001b].

The boresight transformation is required when using the exterior orientation parameters directly. There are two components in solving for this transformation. First is the vector offset between the perspective center of the camera and the center of the INS. The second component is the rotation matrix from the b-frame defined by the INS to the c-frame, or camera optical axis. The determination of the boresight transformation is generally accomplished by comparing the measurements from the GPS/INS to those obtained from an independent aerotriangulation (AT) adjustment. A good AT solution that can be used as a basis for a boresight calibration requires a good-quality test range with targeted points.

Grejner-Brzezinska [2001b] presents a simple model to determine the offset vector between the b-frame and c-frame.

$$\overline{X}_{NED}^{INS} = \begin{bmatrix} X_{INS} \\ Y_{INS} \\ Z_{INS} \end{bmatrix}_{NED} = \begin{bmatrix} X_{PC} \\ Y_{PC} \\ Z_{PC} \end{bmatrix}_{NED} + R_b^{NED} \begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} = \overline{X}_{NED}^{PC} + R_b^{NED} \cdot a^b$$

where a_x, a_y, a_z are the boresight offsets in the b-frame defined by the INS, R_b^{NED} is called the attitude matrix that is developed from the INS measurements, $\overline{X}_{NED}^{INS}$ and $\overline{X}_{NED}^{PC}$ are vectors defining the center of the INS b-frame and the camera projection center, respectively, at some epoch. The subscript NED refers to the North-East-Down local Cartesian coordinate. From the GPS/INS, $\overline{X}_{NED}^{INS}$ is known while $\overline{X}_{NED}^{PC}$ is obtained from the aerotriangulation and R_b^{NED} is obtained from the inertial measurements. The only unknown in this last equation is a^b.

Grejner-Brzezinska [2001b] also describes the determination of the boresight rotation angles. This will involve taking the local reference frame defined by the GPS/INS to the N-E-D system multiplied by the reflection matrix, S. This results in a rotation matrix defined in the photogrammetric reference framework of East-North-Up. Thus,

$$R_b^{ENU} = S \cdot R_b^{NED}$$

where

$$S = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & -1 \end{bmatrix}$$

Defining the attitude matrix determined photogrammetrically as R_φ, then any discrepancy between R_b^{ENU} and R_φ should represent the misalignment that exists between the two systems. The boresight rotation matrix can be presented through the following relationship [Grejner-Brzezinska, 2001b]

$$R_\varphi = R_c^{ENU} = R_b^{ENU} \cdot R_c^b$$

$$\Rightarrow R_c^b = R_b^{ENU} \cdot R_c^{ENU}$$

The final boresight rotation angles can be identified as $\delta\kappa$ or the rotation in heading, $\delta\varphi$ or the rotation in pitch, and $\delta\omega$ or the rotation in roll. They are defined as [Grejner-Brzezinska, 2001b]:

$$\delta\varphi = \sin^{-1} r_{13}$$
$$\delta\omega = \tan^{-1}\left(-r_{232}/r_{33}\right)$$
$$\delta\kappa = \tan^{-1}\left(-r_{12}/r_{11}\right)$$

where

$$\begin{bmatrix} \underline{r_{11}} & r_{12} & r_{13} \\ & \underline{r_{22}} & r_{23} \\ & & \underline{r_{33}} \end{bmatrix} = R_3 R_2 R_1 = R_\kappa R_\varphi R_\omega = R_{\omega\varphi\kappa}$$

and

$$R_{\omega\varphi\kappa} = \begin{bmatrix} \cos\delta\varphi\cos\delta\kappa & -\cos\delta\varphi\sin\delta\kappa & \sin\delta\varphi \\ \cos\delta\omega\sin\delta\kappa + \sin\delta\omega\sin\delta\varphi\cos\delta\kappa & \cos\delta\omega\cos\delta\kappa - \sin\delta\omega\sin\delta\varphi\sin\delta\kappa & -\sin\delta\omega\cos\delta\varphi \\ \sin\delta\omega\sin\delta\kappa - \cos\delta\omega\sin\delta\varphi\cos\delta\kappa & \sin\delta\omega\cos\delta\kappa + \cos\delta\omega\sin\delta\varphi\sin\delta\kappa & \cos\delta\omega\cos\delta\varphi \end{bmatrix}$$

The physical offset of the individual components is usually determined from a conventional survey. Using angles and distances, the relationship between the phase center of the GPS antenna, center of the IMU axis and perspective center of the camera lens can be determined. Since these are not physical entities that the surveyor sees, they are determined

indirectly. For example, the phase center of the GPS receiver may be marked by the manufacturer on the outside of the antenna or by measuring the position of the fiducial marks and knowing the focal length of the camera through a camera calibration report can yield the location of the perspective center of the camera.

The offsets between the components needs to be supplemented with additional information, namely the misalignment of the different coordinate axes of the individual components. Aerotriangulation is used to determine this misalignment, namely the $\Delta\omega$, $\Delta\varphi$, and $\Delta\kappa$ angle differences between the camera coordinate axis and the IMU axis. This is done by comparing the exterior orientation rotational errors derived from the AT process to those measured in direct sensor orientation. As long as the components are not changed, these offsets should remain a constant [Cramer, 1999].

GIS Data Collection

It is well recognized that data collection is the most expensive, or nearly so, aspect of building a GIS. It is also labor intensive. Mobile mapping systems were developed to decrease the cost in data acquisition and increase the turn-around time. Indeed, with current technologies in MMS, the potential for automation exists that should accelerate data collection making it even more economical. Moreover, the accuracy required by the GIS community will also be met with current operational systems. As the technology matures, one should expect to find even greater efficiencies in mobile mapping.

The measurements taken with the sensors on-board the vehicle provide locational information that can be imported into a geographic information system (GIS). Because the features are captured with the cameras, their attributes can also be obtained and input into the GIS as well. This does imply that the attributes are only those items that are visible. For example, while a manhole may be identified when the vehicle is moving, the type of manhole and information about utility facilities within the manhole cannot be captured unless the vehicle stops, the manhole lid is removed, and measurements taken within the manhole. Alternatively, the GIS may contain other data sources that can describe the utility facilities.

The VISAT system uses a structured query language (SQL) to build the database. It also includes other windows that display a multitude of data, such as a base map or aerial/satellite image, a vehicle trajectory window, and measurement window to help locate the features in the object space [El-Sheimy and Schwarz, 1998-99].

Accuracy of Mobile Mapping Systems

Assessment of accuracy of a mobile mapping system involves a complex relationship of a number of sensors along the processing chain. This includes the accuracy of the GPS position, INS position and attitude, identification and measurement of the features on the

imagery, results from the system calibration, distance between the image sensors and the object features, and the image sensor geometry.

The accuracy of GPS is dependant upon a number of variables such as [Cramer, 1999]:

- approach to processing such as absolute or differential,
- observables, and
- satellite geometry.

It is possible to obtain position accuracies in the 10 cm range for baselines up to about 30 km. Moreover, velocity can be determined to a few cm/s.

El-Sheimy and Schwartz [1998-99] tested the VISAT MMS in two different modes: integrated GPS and INS and INS alone. A test field was constructed with 80 control points that were positioned with GPS. For assessment of accuracy, these were treated as "true" values. The distance between the cameras and the control points fell between 10-30 m. Remember that because of the short fixed base between the cameras, distance to the objects should not be too long.

The integrated GPS/INS involves gathering the vehicle navigation data from both sensors and using them together to exploit the measurement of each sensor. This method is the preferred approach in an operational environment, but it does assume a continuous lock on the GPS satellites. The INS only processing method involves ZUPTs at regular intervals. Within an urban area, because the GPS signal can be frequently blocked, this is probably the primary processing method.

The integrated GPS/INS results were found to be 0.13 m in the horizontal direction and 0.09 m in height. These are root mean square (rms) errors. In the INS only results, the rms error was found to be 0.29 m in the horizontal direction and 0.19 m in the vertical. Because El-Sheimy and Schwartz constrained the control values, they feel that the more realistic representations of the rms errors are about 10 cm for the horizontal coordinates and 5 cm for height errors [El-Sheimy and Schwarz, 1998-99]. Grejner-Brzezinska[6] gives an accuracy range of 10-20 cm.

Accuracy in real-time is a little different. As we have seen, accurate positioning requires post processing of the GPS and INS data. Nonetheless, using a free inertial navigation solution, real-time solutions are possible, but only at a lower accuracy because of the time-dependent INS error rate. This is a long-term error. If one uses the INS navigation differences between two consecutive exposures, this long term effect is practically negligible. This has been shown to be of sufficient accuracy for relative orientation purposes. Post processing can be employed to correct the relative orientation in absolute terms. Grejner-Brzezinska and Toth [2003][7] have indicated that using a 1.3 m image

[6] This estimate is based on a 2-m base between the cameras and an object distance of 5-20 m..

[7] This is the second generation mobile mapping system developed by OSU for ODOT and the specifics are discussed earlier.

separation distance, which yields about a 50% overlap that an error in relative orientation of about 50 arc seconds will result in a linear offset of about 0.3 mm, which is negligible for the relative orientation.

Cramer [1999] looked at the accuracy from the point of view of its competition with aerotriangulation. His findings indicate that technically and theoretically, DSO can compete with AT. This means that the main consideration is really one based on economic concerns.

But, as Cramer [1999] also states, the construction of a combined GPS/IMU with aerotriangulation should receive further consideration. While using AT increases the cost, the computational budget is not as significant as it is with AT without GPS/IMU integration. Moreover, this combined AT with GPS/IMU approach is very important in quality control evaluation since the observed orientation parameters are evaluated with the aerotriangulation solution. Direct sensor orientation places a lot of reliance on the performance of individual components such as the precise time alignment, the influence of external force upon the GPS measurements and the accuracy of the interior orientation of the sensor. Therefore, a DSO/AT integrated approach can strengthen the solution, increase the reliability of the results and provide a more robust self-calibration on the whole mapping system.

This same conclusion was reached by Greening et al [2000]. These authors indicate that the results of the camera calibration should be thought of as a priori estimates of the interior orientation parameters that are subsequently massaged or adjusted with the bundle adjustment with self calibration. Errors, even small ones, in critical parameters can have a significant effect on the results. For example, Greening et al [2000], drawing upon results from Dr. T. Schenk, state that a 20 μm error in the calibrated focal length can yield a comparable error of 0.7 m in the object space for mapping camera at a flying height of 5,000 m above ground.

Moreover, there is also an almost linear relationship between the focal length of a camera and temperature. When exposed to temperatures different than those that existed at the time of calibration, the lens cone can experience expansion and contraction. This result is shown in figure 4 [Greening et al, 2000]. Therefore, it is important to see that AT does provide continuing benefit to the mapping process. In fact, Greening et al state that the functions of AT include:

- densification or extension of control over the project area,
- perform self calibration on interior orientation parameters such as the calibrated focal length and other image distortions, and
- execute quality control/quality assurance over the project.

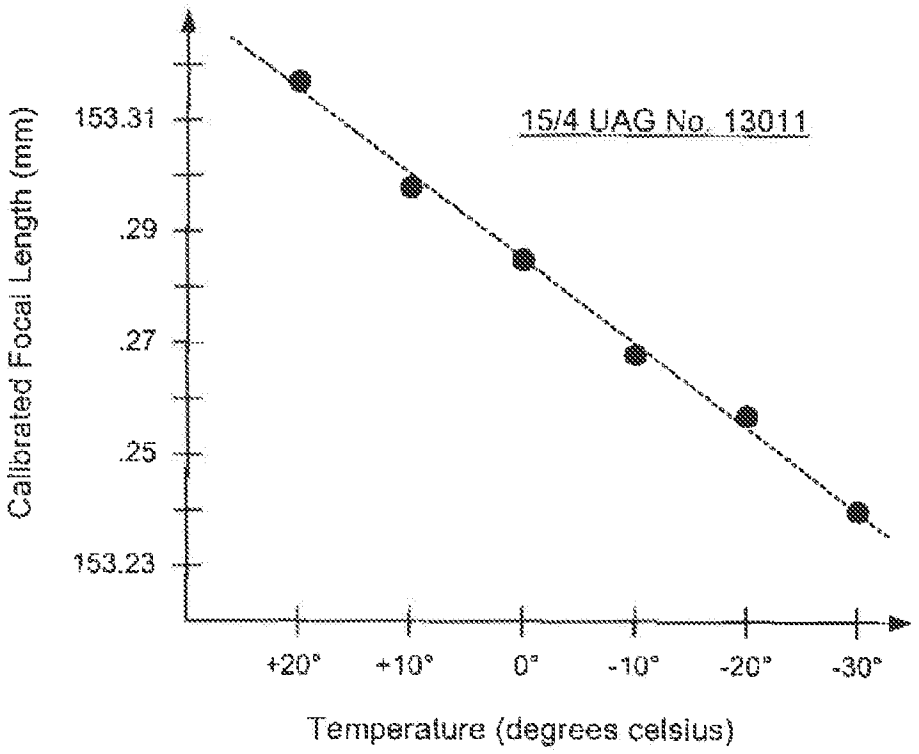


Figure 4. Effect of temperature change on the calibrated focal length [from Greening et al, 2000].

One of the criticisms of direct sensor orientation has been the degradation of stereo viewing within the model. A parallax free model is normally accomplished by visiting points, often referred to as the von Gruber points, where parallax is manually removed. Relative orientation results obtained by manual parallax removal can be different than results obtained from conventional aerotriangulation, which can be further different from direct sensor orientation. As Colomina [2002] states, residual y-parallaxes were accepted in the AT and even airborne GPS aerotriangulation results because of the classical two step orientation process and this can also be handled in the DSO approach by modifying the two step process. This can be shown in figure 5 where tie points could be observed and included in a local bundle solution.

The selection of the object space coordinate system causes an issue in photogrammetry, which could be exacerbated in DSO. Figure 6 shows the effects of the physical geometry in the photography of overlapping imagery and its projection onto a state plane coordinate system. From the figure, the ellipsoid normals are not parallel to each other therefore the distance aa' > bb' > cc' > dd'. This relationship indicates that the ellipsoid normals tend to converge. Thus, the coordinates of the point expressed in the conformal mapping plane with an orthometric height defining the Z-component define a system that is not conformal in the sense that it does not represent the real world situation [Greening et al, 2000]. State plane coordinates represent the projection of curved points onto a flat plane. This cannot be done without any distortion. Along with ellipsoid normals

converging, there is also a projection scale factor. This means that the distance projects on the plane, ee', can differ significantly from the distance aa' that represents the exposure stations of the camera. A more significant problem is that the physical relationship between the ellipsoidal height measured by GPS and the orthometric height are not scale-compatible with the projected points e and e' [Greening et al, 2000].

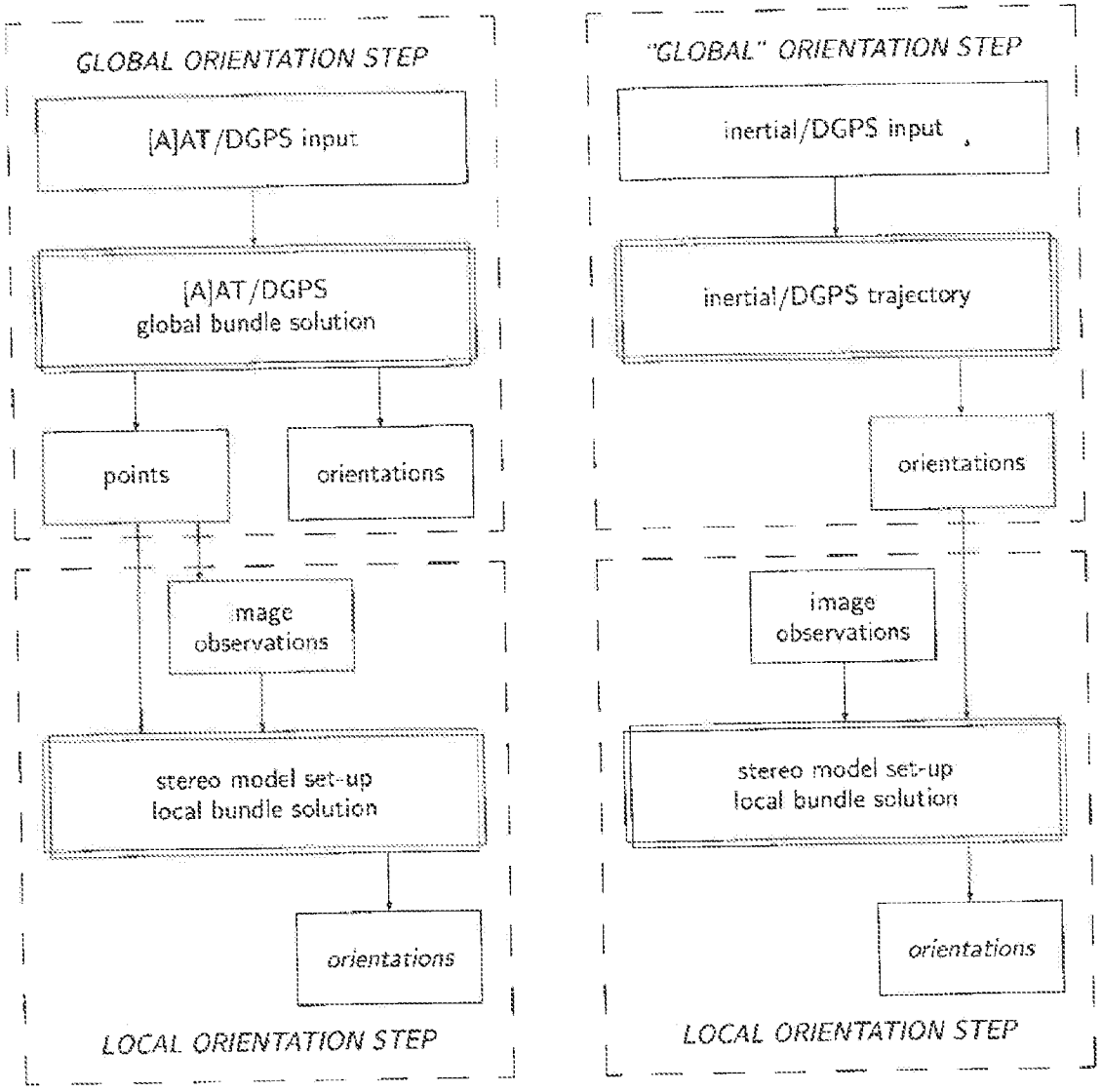


Figure 5. Two step orientation proposal [from Colomina, 2002].

What Greening et al [2000] and others have proposed is the use of local rectangular coordinate system whose origin is near the center of the project. The X and Y coordinates are oriented easterly and northerly respectively with the Z-coordinate approximating the local vertical. This provides a true Cartesian coordinate framework that should be used not only for aerotriangulation but also for map compilation.

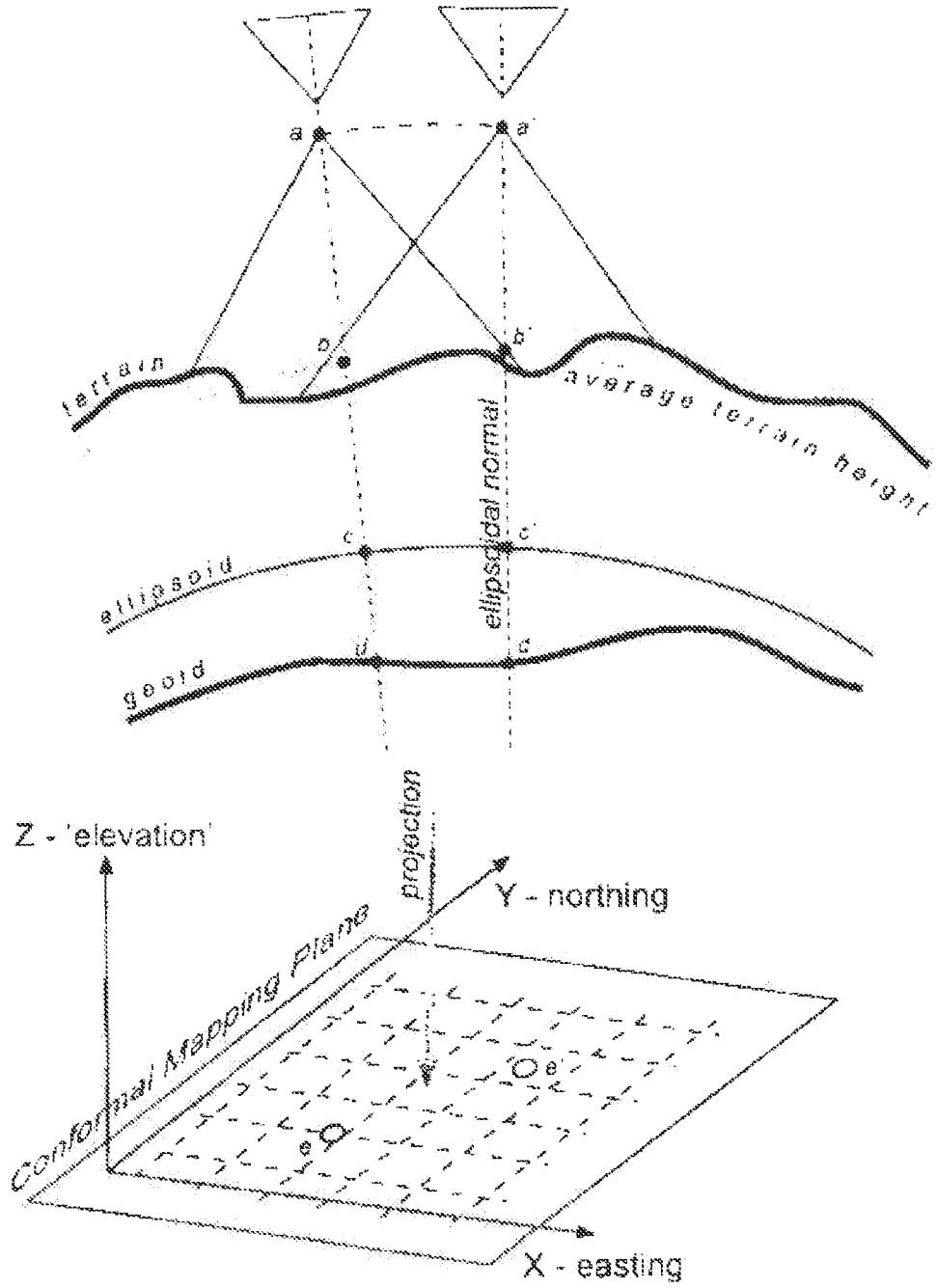


Figure 6. Non-Cartesian coordinates and the effects of scale [from Greening et al, 2000].

A related issue is the geoid and deflections of the vertical. It is well-known that the ellipsoid and geoid are non-parallel surfaces. Additionally, there are no linear relationships between the two reference surfaces. While we know how this geoid separation affects heights, it also impacts on INS derived orientation [Greening et al, 2000]. The orientations

from the inertial system are related to a local level surface which is perpendicular to the local vertical whereas the relationship should be made with respect to the ellipsoidal normal. While it is true that aerotriangulation blocks often use the same scheme, Greening et al indicate that their effects are very localized and therefore insignificant when AT is employed.

As a comparison, Greening et al [2000] performed a test on DSO by comparing the results from three different tests: AT alone, DSO alone, and AT with observed orientation elements. Upon achieving orientation, a compiler looked at the model to evaluate its effectiveness in making stereoscopic measurements. The conventional AT was used as the benchmark since this approach is tried and true within the mapping industry.

The results when using directly observed exterior orientation parameters indicated that about half of the models contained "moderate" to "severe" levels of y-parallax that potentially made the measurements unreliable. On the positive side, the results did indicate that they were accurate enough for ASPRS Class II mapping standards at a scale of 1" = 100' with 2' contours. The last test was to incorporate the observed exterior orientation into the aerotriangulation. Here the results were slightly poorer than the conventional AT alone process, but parallaxes were removed. This result yielded accuracies sufficient for ASPRS Class I mapping standards at a scale of 1" = 100' and 2' contours.

Benefits of Mobile Mapping Systems

There are numerous benefits that can accrue from MMS. Grejner-Brzezinska [2001a] states that "multisensor systems provide complementary, fast, accurate, fault-resistant, and cost-effective data that can be used in a variety of mapping tools". Other benefits include [Grejner-Brzezinska, 2001a; 2001b]

- A cost savings in data collection of around 10:1.
- A reduction of field trips at again a 10:1 ratio.
- Proactive asset management.
- Improved service by reducing turn around time.
- Increased productivity through automation.
- Optimizing data flow.

Conclusion

Mobile mapping is making a significant impact in spatial and attribute data collection for geographic information systems across the world. Future technological developments and a better understanding of the interchange between different sensors will make MMS a more robust and dynamic real-time mapping and information management system.

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Review Questions

1. Describe, in your own words, what a mobile mapping system is in the context of the information given in this lesson.

2. Describe the weaknesses of using a GPS-only navigation sensor.

3. Explain how GPS and INS are complementary navigation systems.

4. One of the issues of GPS is cycle slips. What is a cycle slip? How can they be corrected?

5. Describe, conceptually, how georeferencing of features is performed in a mobile mapping system.

6. What are the advantages of an area CCD array over analog film techniques?

7. Describe issues that the user should be aware of when comparing a CCD array to analog film.

8. What are the benefits of a mobile mapping system?

9. Why is a system calibration important?

10. Describe the factors that affect real-time mobile mapping.

11. What are the sources of error within an IMU and how can these errors be minimized in an inertial-only mode?

12. What are the advantages of direct sensor orientation over conventional aerotriangulation?

13. Describe the boresight calibration. What is it and how is it performed?

BILDMESSUNG UND LUFTBILDWESEN

ZEITSCHRIFT FÜR ALLE ZWEIGE DER PHOTOGRAMMETRIE UND IHRE RANDGEBIETE

Organ der Deutschen Gesellschaft für Photogrammetrie e. V.

Hauptschriftleiter: Kurd Slawik · Berlin-Wilmersdorf · Hildegardstraße 8

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Inhalt: Koneeny, Mechanische Radialtriangulation mit Konvergentaufnahmen, S. 1 / Gotthardt, Vergleichsmessungen mit Stereotop und Aeroprojektor Multiplex, S. 8 / Weimann, Schnittzeichnungen mit dem Stereoplanigraphen, S. 12 / Wirths, Die Anwendung der Luftbildvermessung bei der Herstellung von Katasterkarten in Nordrhein-Westfalen, S. 21 / Haße/Nowatzky, Zum Folgebildanschluß, S. 29 / Dreßler, Luftbild- und Kartenausstellung in Berlin, S. 30 / Berichtigung, S. 32 / Buchbesprechungen, S. 33

Mechanische Radialtriangulation mit Konvergentaufnahmen

Von Dipl.-Ing. C. Koneeny, München

1. Allgemeines

Paßpunktbestimmungen sind wesentlich für photogrammetrische Auswertungen. Wegen hoher Kosten der Paßpunktbestimmung ist man bestrebt, die genaueren geodätischen Bestimmungsmethoden durch wirtschaftlichere Bildtriangulierungen zu ersetzen. Im kleinmaßstäblichen Bereich hat zur schnellen Bestimmung der horizontalen Paßpunkte die Radialtriangulation ihre Bedeutung nicht verloren.

In den letzten Jahren hat man der Konvergentphotogrammetrie wegen der günstigeren Flächenleistung neuen Aufschwung gegeben. Der U.S. Geological Survey verwendet seit 1951 einige 15/23 Doppel-Weitwinkelkammern mit einem Konvergenzwinkel von 40° zur Herstellung von Karten im Maßstab 1 : 24 000. Auch Park Aerial Surveys und AMS verwenden Konvergentweitwinkelaufnahmen für Hochbefliegungen.

Für europäische Probleme der Photogrammetrie kann die Konvergentaufnahme mit der Zeiss-Aerotopograph Normalwinkel-Doppelkammer 2 × RMK 21/18 Anwendung finden. Dr. Brucklacher [1] schildert kurz eine Möglichkeit der Radialtriangulation mit Konvergentaufnahmen.

Der Verfasser hat sich im Jahre 1955 während eines zweijährigen USA-Aufenthaltes damit befaßt, mechanische Radialtriangulationsmethoden auf konvergente Weitwinkelaufnahmen bei einem Konvergenzwinkel von $40^g = 2\gamma$ anzuwenden. Es handelte sich dabei um Tests mit der Bildschlitzmethode und mit Metall-Templets. Die Überlegungen wären jedoch auch für die aus der Praxis verdrängte numerische Radialtriangulation gültig.

Bei der Radialtriangulation werden Winkel im Bild verglichen mit Winkeln in der Natur. Hierbei können 3 bestimmte Punkte als Radialzentren verwendet werden [2]:

1. der Hauptpunkt H,
2. der Nadirpunkt N,
3. der Fokalpunkt F (der winkeltreue Punkt).

Wird $\gamma = 0$ (also bei exakter Senkrechtaufnahme), fallen alle 3 Punkte in einem Punkt zusammen und alle in ihm gemessenen Winkel zwischen Strahlen in Bild und Natur sind gleich. Gewöhnlich werden die Bildwinkel jedoch Verzerrungen wegen Bildneigung und wegen Un-

OFEK07708

ebenheiten im Gelände erfahren. Die radialen Verzerrungen im Bild werden nach Fagerholm [3] für genäherte Senkrechtaufnahmen

$$\text{für den Hauptpunkt:} \quad da = \frac{\nu^2}{4} \sin 2\alpha - \nu \frac{\Delta Z}{R} \cos\alpha,$$

$$\text{für den Nadirpunkt:} \quad da = \frac{\nu^2}{4} \sin 2\alpha,$$

$$\text{für den Fokalpunkt:} \quad da = -\frac{\nu}{2} \frac{\Delta Z}{R} \cos\alpha,$$

wobei ν = Neigung,
α = Winkel des Strahles gezählt von der Neigungsachse,
ΔZ = Höhenunterschied zwischen den Endpunkten eines Strahles,
R = Länge des Strahles.

In der Praxis werden Nadir- und Fokalpunkt wegen Unkenntnis der wahren Neigung meist nicht genau bestimmbar sein; deshalb, besonders aber wegen der sicheren Übertragungsmöglichkeit der Punkte, verwendet man bei Senkrechtaufnahmen näherungsweise radiale Zentren an markanten Bildpunkten in der Nähe der idealen Lage. Die angegebenen Formeln wären nach Fagerholm demnach zu ergänzen, wenn das tatsächliche radiale Zentrum um δ entlang der Neigungsachse und um $\Delta\delta$ senkrecht dazu vom idealen Zentrum entfernt ist, und zwar je um die Ausdrücke:

$$+\left(\frac{\nu}{2}\sin 2\alpha - \frac{\Delta Z}{R}\cos\alpha\right)\Delta\nu - \left(\nu\sin^2\alpha - \frac{\Delta Z}{R}\sin\alpha\right)\xi.$$

Daraus geht hervor, daß die Nadirpunkttriangulation günstiger bei großen Geländehöhen unterschieden ist und daß die Fokalpunkttriangulation den Vorrang für große Bildneigungen einnimmt.

R. Förstner [4] hat die Verhältnisse zwischen den Richtungsfehlern der Hauptpunkt-, Nadirpunkt- und Fokalpunkttriangulation übersichtlich graphisch dargestellt. In seiner Veröffentlichung finden sich auch die Ableitungen der komplizierten strengen Beziehungen für die Richtungsfehler, die für den Senkrechtfall (ν bis 5°) durch Reihenentwicklung in obige stark vereinfachte Form übergeführt werden können.

Die strenge Formel für die Fokalpunkttriangulation sei hier interesseshalber angeschrieben:

$$\operatorname{tg} da = \frac{\frac{\Delta Z}{h}\cos\alpha\left[\sin\alpha\,(1-\cos\nu) - \frac{f}{R}\operatorname{tg}\frac{\nu}{2}\right] + \left[\operatorname{tg}\frac{\nu}{2} - \operatorname{tg}\frac{(\nu-\Delta\nu)}{2}\right]}{\left(1-\frac{\Delta Z}{h}\right) + \frac{\Delta Z}{h}\sin\alpha\left[\sin\alpha\,(1-\cos\nu) - \frac{f}{R}\operatorname{tg}\frac{\nu}{2}\right] - \left[\operatorname{tg}\frac{\nu}{2} - \operatorname{tg}\frac{(\nu-\Delta\nu)}{2}\right]}$$

$$\frac{\left[\sin\alpha\cdot\sin\nu - \frac{f}{R}\frac{\Delta Z}{h}\cos\nu\right] - \operatorname{tg}\xi\cdot\sin\alpha\left[\sin\alpha\cdot\sin\nu - \frac{f}{R}\cdot\frac{\Delta Z}{h}\right]}{\left[\sin\nu\cdot\cos^2\alpha - \frac{f}{R}\cdot\frac{\Delta Z}{h}\sin\alpha\cdot\cos\nu\right] + \operatorname{tg}\xi\cdot\cos\alpha\left[\sin\alpha\cdot\sin\nu - \frac{f}{R}\cdot\frac{\Delta Z}{h}\right]}$$

f bedeutet hierin die Brennweite und h die Flughöhe.

2. Fokalpunkttriangulation

Aus dem Vergleich der Formeln ergibt sich, daß das radiale Zentrum, welches in Abhängigkeit von Neigung und topographischen Unebenheiten die geringsten Fehler verursacht, irgendwo zwischen Nadirpunkt und Fokalpunkt liegen wird. Bei Auswertung der strengen Formeln ergibt sich für 40° konvergente Aufnahmen ein Bereich von $0{,}1 > \frac{\Delta Z}{h} > 0$, in dem

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die Fokalpunkttriangulation günstiger als die Nadirpunkttriangulation sein wird. Das trifft für Hochhebiegungen ebenen und mittelgebirgigen Geländes stets zu.

Kontaktkopien von Konvergentaufnahmen können somit ohne besondere Hilfsmittel direkt zur Radialtriangulation verwendet werden, solange man den Konvergenzwinkel und damit angenähert auch den Neigungswinkel kennt. Die Fokalpunkte liegen senkrecht zur Neigungsachse um $f \cdot \operatorname{tg}\frac{\nu}{2}$ vom Hauptpunkt des Bildes entfernt, angenähert in Flugrichtung bzw. entgegengesetzt. Sie können auf einer transparenten Schablone leicht konstruiert und somit auf die Bilder übertragen werden. Die weitere Übertragung der Fokalpunkte von Bild zu Bild erfolgt stereoskopisch, ebenso die Auswahl und die Übertragung der äußeren Verknüpfungspunkte. Obwohl bei Konvergentaufnahmen das stereoskopische Sehen ohne Vergrößerungsausgleich starkem Zwang unterworfen und nur in der unmittelbaren Umgebung des Punktes möglich sein wird, ist die stereoskopische Punktübertragung nach einiger Übung möglich, besonders wenn man geneigte Bildträger in Verbindung mit einem Spiegelstereoskop verwendet.

Zur Erläuterung des Netzbildes sollen folgende Abbildungen dienen:

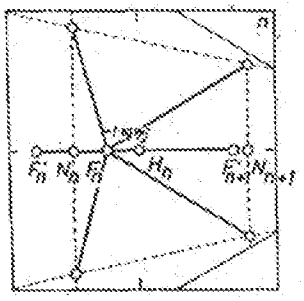


Abb. 1a. Konvergentbild

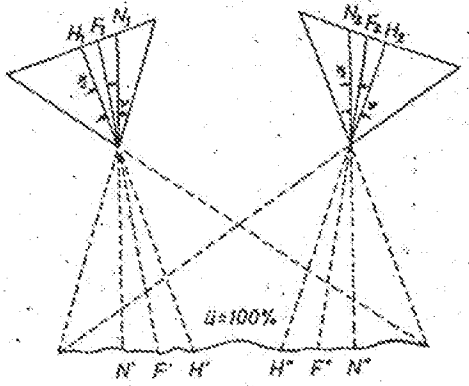


Abb. 1b. Geometrische Zusammenhänge

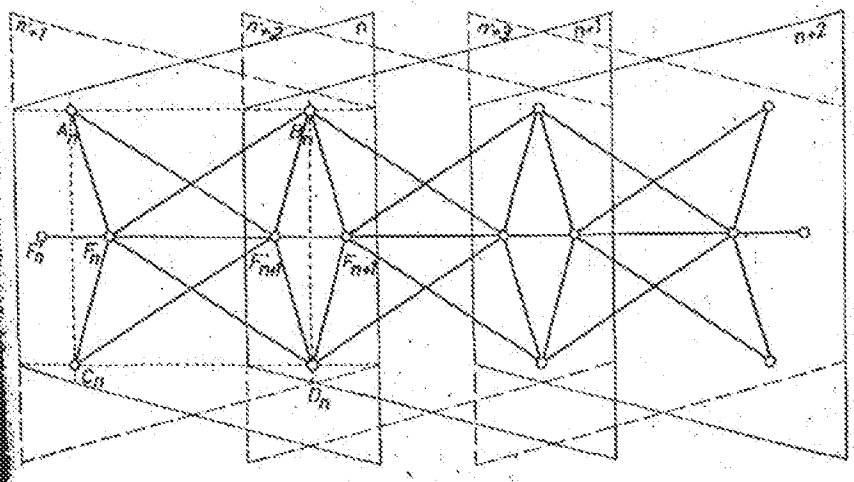


Abb. 1c. Fokalpunktnetz

Abb. 1. Fokalpunkttriangulation

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Im Fokalpunkt F_n ergeben sich 6 Richtungen nach den Punkten A_n, B_n, F'_{n+1}, D_n, C und F'_n. Somit läßt sich ein sehr starres Triangulationsnetz aufbauen.

Wegen der Starrheit des Netzes wird die Fokalpunktmethode in der mechanischen Radial triangulation — um diese handelt es sich in der heutigen Praxis fast ausschließlich — no dann ohne störende Klaffungen möglich sein, wenn die Richtungsfehler klein bleiben. D theoretischen Richtungsabweichungen müssen also wenigstens die Genauigkeiten einhalte mit denen ein Radialpunkt bestimmt und übertragen werden kann. Nehmen wir für die Genauigkeit einen Wert von 0,3 mm im Endpunkt eines Strahles an, so erhalten wir i ungünstigsten Fall bei festem $\nu = 20^\circ$ einen Wert von $\frac{\Delta Z}{h} = 11{,}0‰$. Die Fokalpunkt triangulation kann demnach ausgeführt werden, wenn $\frac{\Delta Z}{h} < 11‰$ bleibt. Zu beachten is daß ζ und $\Delta\nu$ so klein wie möglich zu halten sind, da der durch sie verursachte Fehler e Vielfaches der durch Neigung und Topographie bedingten Fehler erreicht. Es empfiehlt si deshalb, die Fokalpunkte selbst als Radialzentren zu verwenden, auch wenn sie keine ma kanten Punkte im Bild sind. Ihre Übertragung muß besonders sorgfältig durchgeführt werde

3. Nadirpunkttriangulation mit entzerrten Aufnahmen oder Strahlen

Zur Vermeidung der Nachteile, die die Fokalpunkttriangulation mit sich bringt, kann ei genäherte Entzerrung der Bilder um den halben Konvergenzwinkel durchgeführt werde Der Nadirpunkt der Kontaktkopie entspricht dann einem ideellen Hauptpunkt des genäh entzerrten Bildes. Die Richtungsfehler dieser Nadirpunkttriangulation entsprechen dann d Richtungsfehlern einer gewöhnlichen Hauptpunkttriangulation. Der einzige Unterschied lie lediglich darin, daß jeder Nadirpunkt 2 zugehörige Bilder der Koppelkammer hat. In jed der beiden Bilder werden die Richtungen nach je 5 Punkten bestimmt. Zwei der Strahl in der Neigungsachse, sind dabei in beiden Bildern identisch. Dadurch ergibt sich eine dehnte Form eines Rautennetzes.

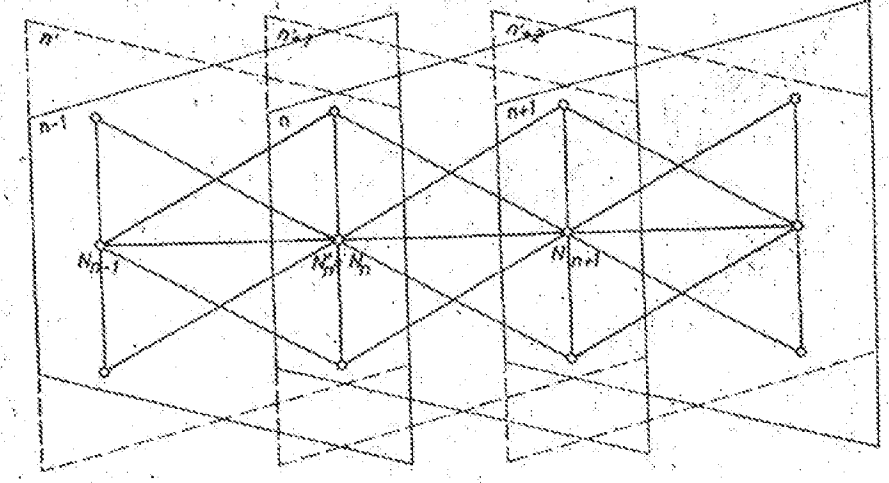


Abb. 2. Nadirpunkttriangulation

Falls $\zeta = 0^\circ$ kann die Richtungsverzerrung völlig vernachlässigt werden. Für $\zeta =$ und 0,3 mm Verzerrung im Endpunkt eines Strahls bei $\nu = 20^\circ$ erhält man einen Grenz von $\frac{\Delta Z}{h} < 11{,}3‰$. Es empfiehlt sich also auch hier die mit einer Schablone gewonn

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Nadirpunkte statt anderer in der Nähe liegender markanter Punkte zu verwenden, damit ε klein gehalten werden kann.

Die Entzerrung kann auf verschiedene Art erfolgen: am einfachsten photographisch mittels eines Entzerrungsgerätes nach Einstelldaten [5]. Von den europäischen Geräten sind für 40° konvergente Aufnahmen das Zeiss-SEG I und das Wild E 2 wegen ihrer großen Neigungsbereiche gut geeignet. Natürlich kann sich die Entzerrung unter Verwendung geeigneter Verfahren auch auf die Strahlen selbst beschränken. Sie kann z. B. graphisch [5] durchgeführt werden.

Eine mechanische Entzerrung der Strahlen erfolgt im Radialsekator RS I von Zeiss-Aerotopograph. Er besitzt als Universalgerät für die Radialtriangulation eine Vorrichtung, Bildneigungen ν bis 22,5° einzustellen und sämtliche Strahlen für das eingestellte ν im Nadirpunkt zu korrigieren. Der Vorteil bei Verwendung des Radialsekators besteht darin, daß eine Nadirpunkttriangulation direkt mit Kontaktkopien ausgeführt werden kann.

4. Stereotempletriangulation

Dehnt man den Begriff der Radialtriangulation auch darauf aus, daß man den Vergleich von Winkeln im Stereomodell mit denen in der Natur einbezieht, so gehört die vom US Geological Survey eingeführte Stereotempletmethode mit in das Gebiet unserer Betrachtung [6].

Die Methode beruht darauf, daß in einem relativ und näherungsweise absolut orientierten Modell die radialen Versetzungen zwischen den Orthogonalprojektionen irgendwelcher Modellpunkte praktisch nicht wirksam sind. Man hat die Methode deshalb hauptsächlich für den Maßstabsausgleich von Aerotriangulationsblöcken verwendet [7].

Bei der Radialtriangulation werden jedoch keine Höhenangaben verwendet. Für die Anwendung der Stereotempletmethode genügt hier also eine angenäherte Horizontierung des Modells etwa nach Wasserläufen. Die Kenntnis des Maßstabs ist dabei unwesentlich. Die Horizontierung des Modells wird meist um so genauer möglich sein, je höher die Aufnahmen geflogen wurden.

Die Wahl des Radialzentrums ist freigestellt, da das Modell ein wahres Abbild der Natur darstellt. Um einen günstigen Maßstabsausgleich zu erhalten, wird man pro Modell zwei diagonal gegenüberliegende Radialzentren wählen (Abb. 3).

Natürlich ist auch eine Anordnung wie bei der Nadirpunkttriangulation möglich (Abb. 2), die sich besonders bei mehreren Bildstreifen empfiehlt [8], da sonst der Anschluß zu starr wird.

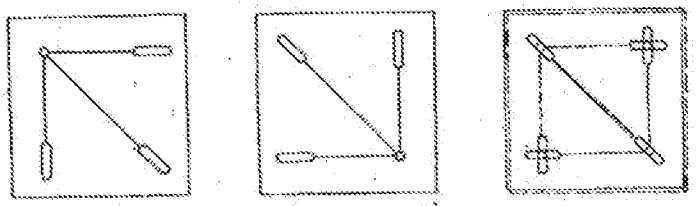


Abb. 3. Stereotempiets

Die Schablonen, in die später Löcher und Schlitze eingestanzt werden, können mit Hilfe eines jeden für Konvergentaufnahmen geeigneten Stereoauswertegerätes gewonnen werden. Ein Gerät 2. Ordnung (Kelsh Plotter mit Pantograph, Multiplex, Twinplex) dürfte zur Herstellung der Templets am wirtschaftlichsten sein.

5. Vergleich der verschiedenen Verfahren

Die drei geschilderten Verfahren wurden praktisch an einem Bildflug aus 10 000 m Höhe erprobt. Die Radialtriangulation bestand aus 2 Streifen mit je 8 Modellen von 100% Überdeckung, aufgenommen mit einer 40°-2×15/23 Mark Hurd-Konvergentkammer mit Metrogonobjektiven. Im 25×100 km großen Testgebiet waren 42 Lagefestpunkte bekannt. Davon

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wurden jeweils 4 bzw. 5 Festpunkte zum Einpassen des Verbandes benutzt, die übrige dienten als Kontrollpunkte. Es standen Kontaktabzüge und entzerrte Bilder im Maßstab 1 : 60 000 zur Verfügung. Als Triangulationsmaßstab wurde 1 : 50 000 gewählt.

Die Ergebnisse seien hier in knapper Form mitgeteilt:

		Maximalfehler		Mittlerer Fehler		Systemat. Anteil		Festpunktverteilung
		Δx_{50mm}	Δy_{50mm}	$m_{\Delta x_{50mm}}$	$m_{\Delta y_{50mm}}$	$t_{\Delta x_{50mm}}$	$t_{\Delta y_{50mm}}$	
Metall-Templet-Methode	Fokalpunkttriangulation	49	32	26	15	13	1	
	Fokalpunkttriangulation	49	30	25	15	11	1	
	Nadirpunkttriangulation	121	101	53	31	29	16	
	Nadirpunkttriangulation	49	82	30	27	6	1	
Bildschlitzmethode	Fokalpunkttriangulation mit einfacher Bildstanze	32	18	12	11	4	2	
	Nadirpunkttriangulation mit einfacher Bildstanze	37	29	20	17	5	1	
	Nadirpunkttriangulation mit Radialsekator	18	21	8	7	0	5	
	Stereotemplets	16	19	5	7	0	5	

Die Übersicht zeigt sofort, daß die Ergebnisse mit den Metall-Templets im Vergleich z Bildschlitzmethode als unbrauchbar erscheinen müssen. Die Fehler werden wahrscheinl durch Torsion der Metallarme und durch Verdrehungen der einzelnen Arme gegeneinand beim Zusammenschrauben der Lazy-Daisy-Templets verursacht. Das Verhältnis der Genau keit der Metall-Templet-Methode zur Bildschlitzmethode entspricht den in [3] veröffentlich Ergebnissen Fagerholms für Senkrechtaufnahmen.

Bei den Nadirpunkttriangulationen erkennt man die starke Abhängigkeit von der F punktaufhängung des Verbandes. Erst bei 5 verwendeten Festpunkten erhält das N genügende Stabilität. Das Fokaltriangulationsnetz dagegen ist starrer und liefert dah bessere Ergebnisse; die äußeren „Rautenpunkte" werden dort von 4 Strahlen bestimmt, der Nadirpunkttriangulation nur von 3 Strahlen.

Sowohl Fokalpunkt- als auch Nadirpunkttriangulation, durchgeführt mit der einfach Bildstanze, sind gegenüber der Nadirpunkttriangulation mittels des Radialsekators im Na teil. Der Grund hierfür liegt in Ungenauigkeiten beim Übertragen und Stanzen der Trian lationspunkte, die Fagerholm in [3] schon für Senkrechtaufnahmen als eine Hauptfehlerq bei der mechanischen Radialtriangulation ansieht. Diese wird beim Radialsekator du Lupenbetrachtung des Bildes beim Stanzen herabgemindert.

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Die Stereotempletmethode schließlich hat bei ebenem Gelände die geringsten theoretischen Fehler zu verzeichnen. Fehler der Übertragung schalten aus, da die Radialpunkte im Modell eingestellt und mittels eines Pantographen bzw. Koordinatographen gleich auf Schablonenmaßstab stark verkleinert werden. Es wirken sich praktisch nur die Fehler der Stanzungenauigkeit aus, die der Radialsekator vermindert. Deshalb sind die Ergebnisse von Stereotempletmethode und Nadirpunkttriangulation mittels Radialsekator als gleichwertig anzusehen.

Der Zeitbedarf für die verschiedenen Verfahren war folgender:

Fokalpunkttriangulation mit einfachen Geräten	36 Bilder	10 Stunden
Nadirpunkttriangulation mit einfachen Geräten	36 Bilder	9 Stunden und zusätzlich 4 bis 8 Stunden für Entzerrung
Nadirpunkttriangulation mit Radialsekator	36 Bilder	6 Stunden
Stereotempletmethode	16 Modelle	20 Stunden

Es ist dem Verfasser klar, daß ein allgemein gültiger quantitativer Vergleich der Methoden aus dem vorhandenen Bildmaterial nicht möglich ist. Desgleichen kann die Frage der Fehlerfortpflanzung der meist systematischen oder pseudosystematischen Radialtriangulationsfehler nur durch Verwertung von ausgedehnterem Bildmaterial geklärt werden. Es konnte jedoch festgestellt werden, in welcher Weise sich die einzelnen Methoden für die Radialtriangulation eignen. Schließlich läßt die Übereinstimmung in der Größe der Fehler bei Senkrecht- und Konvergentaufnahmen vermuten [3], daß nicht die theoretischen, sondern die mechanischen Triangulationsfehler bei der mechanischen Radialtriangulation ausschlaggebend sind.

Zusammenfassung

Es wird über drei Verfahren berichtet, die mechanische Radialtriangulation mit Konvergentaufnahmen durchzuführen: die Fokalpunkttriangulation mit Kontaktkopien, die Nadirpunkttriangulation mit genähert entzerrten Aufnahmen oder Strahlen und die Stereotempletmethode. Die genauesten Ergebnisse werden durch Stereotemplets und durch Nadirpunkttriangulation mittels des Zeiss-Radialsekators RS I, der eine mechanische Entzerrungsvorrichtung besitzt, erzielt. Die Fehler der Radialtriangulation mit Konvergentaufnahmen entsprechen größenordnungsmäßig den Radialtriangulationsfehlern mit Senkrechtaufnahmen.

Summary

It is reported about three methods to perform mechanical radial triangulation with convergent photographs: the isocenter-triangulation with contact prints, the nadir-point triangulation with approximately rectified prints or rays, and the stereo-templet-method. Most accurate results are achieved by stereo-templets and by nadir-point triangulation using the Zeiss-Radial Secator RS I, having a mechanical device for rectification. The errors caused by radial triangulation with convergent photography correspond in magnitude to the radial triangulation errors with vertical photography.

Résumé

On parle de trois méthodes d'exécuter la triangulation radiale mechanique avec des images convergentes: la triangulation à point focal avec contre-positifs, la triangulation à point nadiral avec des images ou rayons approximativement redressées et la méthode des Stereo-Templets. Les resultats plus exacts sont obtenues par les Stereo-Templets et par la triangulation à point nadiral avec le Zeiss Secateur Radial RS I, qui a une appareil mechanique pour le redressement des rayons. Les erreurs de la triangulation radiale avec des images convergentes sont à la même magnitude que les erreurs de la triangulation radiale avec des images verticales.

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OFEK07715

ASPRS/ACSM/RT 92

TECHNICAL PAPERS

VOLUME 5
Resource
Technology 92

gricultural land, with its well defined fences, gates, roads and shelter belts, ilities aircraft navigation and enables very accurately positioned coverage to be ined. It is therefore possible to capture high resolution, large scale images of these with little difficulty.

CONCLUSION

notogrammetrist's View

orne video is a potentially valuable tool for forest health assessment, forest map ating, and disaster evaluation. It does not replace aerial photography mainly use its resolution is so much lower. However, its versatility means that it can ide imagery under conditions which are unsuitable for aerial photography and re high resolution is not required. Further advantages include real-time control nage quality, zoom capability for spot sampling, up to 3 hours of imagery on a le tape, and the immediate availability of the imagery. Airborne video is refore a valuable and versatile new tool for both resource managers and archers.

and Manager's View

evaluation has shown that airborne video can provide a wide range of natural urce information at a level consistent with present management requirements. particular: vegetation mapping; storm, insect and animal damage to forests; weed sion of natural areas, and natural area inventory could greatly benefit from ess to airborne video imagery. Specialized management areas such as logical sites surveys, coastal resource inventory and recreation could also w on this new technology. While there are many applications which require the ition of aerial photographs, a large part of resource management's information irements from remote sensing could be provided by airborne video. Furthermore, information can be taken directly from the video imagery without further image essing. Airborne video could provide a quantum leap in the availability of usable agement information for natural resource management at an affordable price.

orest Health Researcher's View

le aerial evaluation and monitoring of insect, disease, and climate damage was a ificant advance over ground surveys, the methods are still plagued by the inherent curacy of sketch mapping, the lack of an objective record, and the difficulty of erpreting visual information in a noisy, uncomfortable environment. Airborne eo is an outstanding tool for the forest health specialist; it presents real-time agery for assessment of quality, coverage and target definition by the operator; it duces a permanent record that can be analysed at leisure in a quiet, comfortable ironment; and it can produce images which can be manipulated in a computer ironment for use with Geographic Information Systems. While acknowledging borne video's obvious limitations in image resolution and perspective distortion, s technology is certain to revolutionize the way we monitor, map and document the rity of forest health problems. A number of the limitations identified in this lication could be overcome by more problem specific application of the system.

ACKNOWLEDGEMENTS

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USE OF COLOR AIRBORNE VIDEOGRAPHY IN THE U.S. FOREST SERVICE

Richard J. Myhre
U.S. Forest Service
Forest Pest Management
Methods Application Group
Fort Collins, Colorado

INTRODUCTION

Airborne videography is emerging as another remote sensing tool available to forest resource managers. The U.S. Forest Service has been developing and evaluating video image acquisition and analysis technology for use in resource management applications. Combining a high-quality, Super-VHS video camera system with Global Positioning System (GPS) navigation, and image processing and analysis techniques, forest pest management specialist will be able to detect and monitor pest activity over forested areas. Although the development and evaluation of airborne video was directed toward forest pest management applications, the utility of this technology is evolving into other resource management disciplines.

Videography offers many advantages over more traditional methods of pest detection and monitoring, including lower cost than ground methods, higher accuracy than conventional aircraft-based sketchmapping surveys, and faster turnaround time than conventional aerial photography methods. Video data can quickly be converted to a digital form for analysis and integration into a geographic information system (GIS) environment. This paper will present an overview of the airborne video image acquisition system, and a discussion of image processing methods.

THE ROLE OF AIRBORNE VIDEOGRAPHY

It is important to understand the role videography can play in the pest management arena related to existing aerial survey technologies. Forest Pest Management (FPM) has the responsibility for the detection, evaluation, and control of insect and disease impacts upon the Nation's forest resources. Resource managers require estimates of the location and intensity of pest damage to plan and conduct suppression or salvage programs. Often, these estimates are obtained from aerial detection surveys conducted for the purpose of discovering pest outbreaks when they first appear or are in the developing stages, and to monitor changes.

Often these surveys are flown as part of an ongoing systematic monitoring plan. Historically, aerial detection surveys have been of two basic types: (1) visual sketchmapping surveys, and (2) aerial photography surveys.

Visual Sketchmapping Surveys

Visual sketchmapping is the technique of delineating the area of pest-caused damage onto maps based on observations by a pest specialist flying in a small aircraft. Aerial sketchmapping has

been the most efficient and economical method of detecting and appraising recognizable pest damage over large remote forest areas. Sketchmapping is highly subjective, however; the resulting data can be no more accurate than the competence of the sketchmapper and the conditions under which the data were obtained. No two sketchmappers will and can be expected to record the same pest outbreak in exactly the same way. For this reason, sketchmapping should be regarded more as an art than as an exact science (Klein et al. 1983).

When an outbreak is detected, its causal agent and host are identified, and its location is marked on the survey map. Sketchmap surveys are used to record current year defoliation and mortality, locate new infestation areas, detect new and potential pest problems for ground evaluation, stratify damage intensity for aerial photographic surveys, and provide records of pest outbreaks and their rate of spread. Although annual sketchmap surveys supply resource managers with current and useful information about the status of pests, more reliable remote sensing techniques could provide improved data on the location and extent of the pest damage.

Videography has demonstrated the following advantages over conventional aerial survey techniques (sketchmapping) for detection and monitoring:

1. The system can be installed in most of the small survey aircraft now used for conventional sketchmapping.

2. Video tape provides a permanent record of conditions as they exist at the time of the survey.

3. Videotaping eliminates the subjective evaluation of the observer while in flight.

4. Videography provides improved positional accuracy of the map location of the data collected.

5. Video provides more accurate estimates of the areal extent and severity of pest damage.

Aerial Photographic Surveys

Aerial photography is another available survey tool for forest pest management. Color and color-infrared photography are valuable tools for assessing insect and disease activity on forest lands. Photography has been used to estimate current and/or total levels of damage and mortality from pests. Photos provide a historical record of pest activity and have been used to monitor the rate of spread and trends of a pest over time. Chemical, biological, and cultural treatment methods can be evaluated using aerial photography to determine the vegetation damage prevented.

Most aerial photography applications in pest management can be divided into two broad classes -- mapping photography and sampling photography. Mapping photography is generally used for mapping the total extent of a pest problem (delineating polygons of damage), or mapping a pest's vegetation type. This type of photography usually covers a large ground area and therefore enables the photointerpreter to observe various patterns, trends, and

distribution of the pest activity. Sampling photography is generally used with some type of survey sampling design. This types of photography is used when it is not operationally feasible or cost effective to evaluate 100 percent of the area of concern. A sampling design utilizing aerial photos can be used to obtain an estimate of pest activity and the photo estimate can be strengthened by ground sampling. Since most sampling photography is acquired at larger photo scales, the interpreter can obtain more reliable data, such as tree counts, identifiable pest symptoms and tree species, etc. (Myhre 1988).

Airborne videography should not be viewed as a replacement for aerial photography, but can be substituted for photography when resource activities do not demand the quality and cost of photography. There are many resource activities where remote sensing and aerial photography data are not being used, primarily due to cost. These gaps could be filled by using airborne videography techniques (Myhre et al. 1991). Listed below are attributes of videography that offer advantages over conventional aerial photographic film and camera systems.

1. Imagery is available immediately, making video particularly useful in applications requiring rapid turnaround time such as pest surveys and disaster assessment (i.e., fires, flooding, severe storm damage, etc.).

2. The operator can view "live" imagery on a monitor in the aircraft concurrent with the acquisition, making the video acquisition process less subject to error than that of photography. The image display allows camera exposure settings to be adjusted interactively.

3. The audio track permits notation of pertinent information, which may be of use in future analysis, directly onto the video tape while in flight.

4. A straightforward pathway is provided from the video tape to digital format for computerized image processing and incorporation into a geographic information system (GIS).

5. Video cameras and video tape are lower in cost than conventional aerial photography cameras and film.

6. Airborne video improves the success rate of acquiring the desired coverage at a given point in time. This is especially important when narrow biological windows are involved.

7. Video cameras have higher light sensitivity than film cameras allowing useable imagery to be acquired under less than ideal weather conditions.

8. Video is useful in locations where aerial film and processing may be difficult to obtain.

BACKGROUND AND DEVELOPMENT OF AIRBORNE VIDEOGRAPHY

Interest in video technology was generated within Forest Pest Management (FPM) as a tool to enhance and supplement the existing sketchmapping survey techniques, or to fill gaps where aerial photography surveys are not being utilized due to cost. Video technology has been evaluated by the Methods Applications Group (MAG) of FPM for pest management applications.

In the mid-1980's improvements were made in image quality, affordability, and portability that made video equipment increasingly viable as a remote sensing tool. In 1986 a test was conducted to evaluate the operational feasibility of a color infrared (CIR) video camera for forest pest problems. The camera used in this test was a prototype CIR camera developed by the University of Minnesota, and is now marketed under the trade name Blovision*. The objective of this assessment was to determine if CIR video imagery obtained with an airborne video camera is capable of detecting aerially visible tree defoliation and mortality caused by forest insects. Two general conclusions were apparent from the examination of the video imagery, sketchmap data, and aerial photography. First, the degree of detail possible in mapping classes of defoliation from video is superior to that obtainable via the sketchmapping technique. Second, the positional accuracy of polygons (map locations) of insect damage appears to be greater when using video imagery (Munson et al. 1988). The discouraging part of the test was the poor resolution of the CIR tube camera. However, enough positive results were obtained from this assessment that FPM/MAG decided to continue pursuing this technology.

In 1988, following the CIR video test previously discussed, MAG personnel evaluated the status of commercially available video technology that could be adopted for airborne use. Our intent was to eventually deploy video systems to multiple field locations, so we restricted our evaluation to commercially available "off-the-shelf" technology. The evaluation produced the following information:

1. New solid-state cameras using charged couple device (CCD) sensors are superior to tube cameras. Solid-state cameras are less prone to damage from vibration making them more suitable for aircraft operation.

2. Shuttered video cameras are available that produce higher quality imagery by reducing blur from image motion and vibration that arise in airborne operations.

3. A new recording system called Super-VHS (S-VHS) is now available. S-VHS has several advantages over VHS, including increased resolution (400 lines of horizontal resolution for S-VHS vs 240 lines for VHS), improved color quality, and, improved signal-to-noise ratio through increased band width.

* Mention of commercial products is for convenience only and does not imply endorsement by USDA Forest Service.

Based on the new advancements in video, FPM/MAG personnel developed an airborne video package suitable for addressing forest pest management applications. This package consists of an airborne video image acquisition module and a video image processing module (Myhre et al. 1990).

Video Image Acquisition System

The airborne video image acquisition system developed by FPM/MAG consists of a variety of components that have been consolidated into one package. Many of these components are commercially available from various vendors, while a few components essential to linking the system have been developed by MAG. The specially designed items include the video camera mount, electronic junction box, and specialized cabling. These components were custom-made commercially.

The airborne system has been developed and field tested using the equipment discussed later in this paper. Using equipment or components other than the specified items may result in malfunctions, loss of image quality, or problems with image processing techniques.

Video Image Processing System

Once video imagery has been successfully captured on tape, it can be used immediately in management applications. This use can be as simple as viewing the video tape on the monitor or using the imagery to do sketchmapping in the office. There are, however, more sophisticated tools for using video imagery. MAG has been using the Map and Image Processing System (MIPS), a product of MicroImages Inc. of Lincoln, Nebraska. MIPS runs in a DOS operating environment on any 80386 microcomputer with a math coprocessor. The software supports an array of peripheral devices including digitizers, plotters, color printers, scanners and optical disc drives.

MIPS offers the advantage of being able to capture video frames from tapes and convert them to a digital form. In MAG's case, the frames are captured as TARGA files, but other formats are supported. Once the frames are stored as digital images, they can be geometrically corrected to a map base and mosaiced. The software permits the user to annotate polygons of pest activity using a cursor on the screen. This digital data can be moved easily to a variety of geographic information systems for use and analysis with other data. There are a number of other image processing systems in the market place with similar capabilities (Pywell et al. 1992).

Since each captured video frame is stored in an individual computer file, a mechanism for indexing and retrieving the files in an efficient manner is desireble. The HyperIndex module of the MIPS software is a means of indexing a wide range of geographic data, including scanned maps, photographs, vector data derived from image interpretation, video frames, and satellite imagery. HyperIndex is a process for geographically cross-indexing object/images so that they can be automatically retrieved in a hierarchical fashion by selecting and pointing to the feature of interest with a mouse. By using HyperIndex, the pest specialist or resource manager can have instant pictorial data available to be viewed, and can be used to show change over a given period of time, such as historical references or monitoring pest activity.

THE AIRBORNE VIDEO IMAGE ACQUISITION SYSTEM

Airborne videography has undergone an ample amount of evaluation and testing to demonstrate this technology has definite applications to forest pest management activities. The video system is designed to be installed in small aircraft such as those used for the sketchmapping survey flights. This capability will allow more users to become operational with videography technology than they would with aerial photography technology (especially 9 by 9 inch format camera systems). The real advantage of implementing videography at the field unit level is the utility of a remote sensing tool in the hands of the local resource expertise that know the country and the problems.

Airborne System Components

The airborne video image acquisition system currently in use by FPM is comprised of the following components, each of which is essential to the operation of the system and the acquisition of video imagery:

Video Camera. The video camera includes three major features: (1) Super VHS (S-VHS) recording format, (2) solid-state chip sensor consisting of three charge-coupled devices (CCD) sensors responsive to red, green, and blue light, and (3) a variable, high-speed electronic shutter system for reducing image motion and blurring. Camera accessories include a zoom lens (15x) with remote control for zooming and exposure or illumination control, an electronic viewfinder, and a tripod-mount adapter to attach the camera to the camera mount.

Camera Mount. The mount was designed to hold the camera in a vertical position over an aircraft camera hole; and handle corrections for tip and tilt, and drift rotation.

Video Recorder. A portable S-VHS recorder is used for recording both video imagery and audio notes during the mission flight.

Video Monitor. A color monitor is used while in-flight to observe what is being recorded and to adjust the camera for image quality.

Power Converter. The airborne video system requires 12 volts DC to operate. Most aircraft have 24-28vDC electrical power and require the use of a 28vDC to 12vDC power converter.

Caption Generator. The caption generator links the video camera, recorder, and an aircraft navigation system (a LOng Range Aid to Navigation (LORAN)) unit or a Global Positioning System (GPS) unit. The caption generator allows the user to overlay the date, time, latitude and longitude coordinates, and true heading of the aircraft onto the video frames when using LORAN. Altitude and GPS time may also be displayed when using GPS. The overlayed information helps the user locate and interpret the video imagery after the flight.

Electrical Junction Box. The junction box was designed to help connect all of the various cables and components of the airborne video system.

Cabling. The total system requires a number of cables and connectors to link the various components together. Most of the cables are commercially available and accompany the manufacturers components, while a few of the cables were specially designed.

Electronic Navigation Equipment. Although navigation systems are not actually a component of the video system, they are a very important linkage to the system, and play a key role in the overall airborne system operation. There are two types of electronic navigation systems that have been tested with this video system - LORAN-C, a groundbased radio navigation system; and GPS, a satellite radio navigation and positioning system. Navigation systems are linked to the caption generator through an RS-232 interface.

Together these components provide a compact and versatile image acquisition system. They fit easily into almost any small, single engine aircraft having a 6-inch or larger camera hole. As the system provides instant feedback on image coverage and quality, users can quickly become proficient in its use.

Video technology is rapidly changing; and new, emerging technologies will be a part of the future. In order to deliver an operational system, the status of MAG's 1991 developments reflect the system discussed here. MAG will continue to evaluate the status of new video technologies and when appropriate, upgrade the system.

SUMMARY

The technology is relatively inexpensive to acquire and use. Field-level personnel with little or no remote sensing background can be trained quickly to operate the equipment efficiently.

Although the video developmental efforts at FPM/MAG have been centered around pest management activities, it is apparent that this technology has a wider range of applications and uses for other resource management disciplines. Almost as soon as these video units became operational, field personnel began finding new applications for the systems. Video imagery has been acquired of a variety of resource interests and disciplines. Video shows potential applications for post-fire evaluation (mapping burned areas), range management, recreation, riparian/stream habitat, storm damage assessment, wetland mapping, and wildlife surveys. This paper will not attempt to cover the variety of applications of videography, as other papers given at this conference deal with specific applications of this technology.

In conclusion, the important point to be made here is that no one remote sensing system or method will meet all aerial survey needs and data requirements. Sketchmapping, aerial photography and videography each have their advantages and disadvantages. The resource manager or specialist must address the airborne technique to the survey design and the resulting information/data required.

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GLOBAL CHANGE AND THE NATURAL RESOURCE MANAGER

William T. Sommers
Forest Fire and Atmospheric Sciences Research
USDA Forest Service
Washington, DC 20090-6090

ABSTRACT

Global change has focused public and policy interest on the potential for climatic warming and other atmospheric effects such as stratospheric ozone depletion and acidic deposition. While anthropogenically caused change in the physical and chemical make-up of the atmosphere is of interest itself, the potential impacts of these predicted atmospheric changes on the terrestrial ecosystems that sustain life on Earth are of far greater importance. Global change is essentially a long term resource management issue. The role that the natural resource manager will play in meeting the challenge of global change impacts will be a critical factor in our ability to sustain our environmental and economic systems. That role needs to be realistically appraised and defined by the public and the natural resource manager. Part of the appraisal process should focus on the relative risk of proposed actions in view of a changing background fabric of climate.

INTRODUCTION

The international science community has issued a series of predictions of global atmospheric change which, if correct, will result in heretofore unexperienced events and outcomes for our forests. Convincing the public, and their natural resource managers, of the need to examine opportunities to respond to the effects of global warming on forests must be high on the agenda of the science community. The opportunities we examine should derive from an understanding of the role of the natural resource manager and how that role is likely to be affected by the predicted events and outcomes. This is so because the Earth's forests are vital to the Earth's environmental and economic well being, and the natural resource managers are stewards of those forests.

Three biological systems - croplands, forests, and grasslands (savannahs) - support the world economy (Brown 1990). They supply all the renewable raw materials for industry. With the exception of seafood, they supply all of the World's food. The energy that fuels our bodies and our cars is available to us because plants can combine water and carbon dioxide to convert solar energy to carbohydrates through photosynthesis. 55% of the photosynthetic activity on Earth takes place on the 30% of the Earth's surface that is land. The energy stored in plants, and in other life forms through the food chain, has been laid down for millennia in fossil fuel depositories. In the last few hundred years, we have drawn down the Earth's stored fossil fuel accounts to provide a less laborious life for humankind. At the same time, our growing world population has required ever

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Towns get new view from above

Picture system considered valuable municipal tool

By David Rattigan, Globe Correspondent, 9/5/2002

When Andover received its copy of the new "Pictometry" system, its Fire Department wasted no time putting it to use. Deputy Fire Chief James Lynch used it to map out a safety plan for the town's annual Independence Day fireworks display.

"Last year some material fell into the crowd, so we wanted to set people back [an additional] 50 feet," Lynch said. Dragging the cursor across a desktop site of the city's athletic fields, he was able to measure the distances from the shooting point, and draw a new perimeter. "I could do it without going into the field, and without having to measure it off by hand."

A group of communities northwest of Boston are the first in the state - and among the first in the country - to purchase the Pictometry system, which promises to be a valuable tool for police, fire departments, assessors, planners, inspectors, conservation departments, engineers, community development departments, and others.

Planners and engineers have used aerial photos for mapping and planning for many years, but Pictometry offers more images, from higher and lower points, and with oblique (45-degree) as well as orthogonal (straight-down) angles. The images can integrate with Geographic Imaging Software and its own Electronic Field Study software to measure length, area, or distance; determine longitude, latitude, and altitude; fix the bearing of a road and angles of intersecting roads; calculate perimeter and acreage, and more. As a result, Merrimack Valley Planning Commission executive director Gaylord Burke said, users can "take a field trip on their desktop."

Andover planning director Stephen Colyer, who is also chairman of the Merrimack Valley Planning Commission, was immediately impressed. "The measurement tool is extremely accurate," he said. "I tested it out on some things I knew the measurement of, and it measured both horizontally and vertically. The only error is the error you might make, and where you put the pointer. It's unbelievable."

Timothy Belcher, GIS project manager for the Lawrence Planning and Development Office, said the system is providing him with new, updated aerial images. He envisioned being able to overlay the city's GIS data into the software. "If somebody's interested in a certain site, we can go to the picture, look at it, and then pull up the data as well," he said.

The Merrimack Valley Planning Commission helped arrange the two-year purchase of the licensed system, making it the first regional council in the United States to acquire the technology. Among participating communities, the system has been delivered to Amesbury, Salisbury, West Newbury, Haverhill, Methuen, Andover, North Andover, and Lawrence. Newburyport, Georgetown, and Groveland have purchased it and are anticipating delivery. The purchase price was approximately $160,000 for two years, with communities paying different shares of the total depending on their land size and the package of images they bought. Communities can update every two years. The highest share was paid by Andover, which has 32 square miles, got an extensive library, and paid $10,700 per year. The lowest

was Lawrence, $2,200.

The system was delivered in June and July to most communities, which are loading it into their own systems and training employees.

Pictometry Inc. president and CEO Richard A. Kaplan called the Merrimack Valley Planning Commission communities "our beta site in Massachusetts." He said the Massachusetts Department of Transportation has hired the company to map the rest of the state.

Local officials charged with public safety said they are excited about its potential, as both a training tool and for field use.

Andover's Lynch said a dispatcher could call up an image, and determine whether there's a potential danger, such as a liquid propane tank. "If we're fighting a brush fire, they can warn us if there are any hazards in the area," he said. "No question, it's a great tool."

In a hostage situation, high-risk warrant service, or drug raid, police could learn where they might encounter fences or other obstacles, and possible ambush points.

"From a S.W.A.T. perspective, these are invaluable," said North Andover Police Chief Rick Stanley, who is also control chief for the Northeastern Massachusetts Law Enforcement Council's Regional Response and S.W.A.T. team. "You can look at it and see what you're getting in to, without having to send real bodies in."

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Digital image georeferencing from a multiple camera system by GPS/INS

Mohamed M.R. Mostafa [a,*], Klaus-Peter Schwarz [b]

[a] *Applanix Corporation, 85 Leek Crescent, Richmond Hill, Ontario, Canada L4B 3B3*

[b] *Department of Geomatics Engineering, The University of Calgary, Calgary, Alberta, Canada T2N 1N4*

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Abstract

In this paper, the development and testing of an airborne fully digital multi-sensor system for digital mapping data acquisition is presented. The system acquires two streams of data, namely, navigation (georeferencing) data and imaging data. The navigation data are obtained by integrating an accurate strapdown inertial navigation system with a differential GPS system (DGPS). The imaging data are acquired by two low-cost digital cameras, configured in such a way so as to reduce their geometric limitations. The two cameras capture strips of overlapping nadir and oblique images. The GPS/INS-derived trajectory contains the full translational and rotational motion of the carrier aircraft. Thus, image exterior orientation information is extracted from the trajectory, during post-processing. This approach eliminates the need for ground control (GCP) when computing 3D positions of objects that appear in the field of view of the system imaging component. Two approaches for calibrating the system are presented, namely, terrestrial calibration and in-flight calibration. Test flights were conducted over the campus of The University of Calgary. Testing the system showed that best ground point positioning accuracy at 1:12,000 average image scale is 0.2 m (RMS) in easting and northing and 0.3 m (RMS) in height. Preliminary results indicate that major applications of such a system in the future are in the field of digital mapping, at scales of 1:5000 and smaller, and in the generation of digital elevation models for engineering applications. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: GPS/INS; Georeferencing; Mobile mapping; Multi-sensor systems; Airborne digital mapping; Digital camera

1. Multi-sensor systems for mobile mapping

During the past two decades, the mapping sciences have progressively moved towards digital mapping, making use of multi-disciplinary developments in the geomatics field. Instead of regarding geodesy, photogrammetry, and remote sensing as separate sciences, they are seen more as an integrated discipline today. Part of this development has been spurred on by systems capable of acquiring and fusing accurate globally referenced data in fully digital form with short turn-around-time in a cost-effective fashion. A mobile-mapping multi-sensor system is, thus, the product of integrating the concepts of kinematic geodesy and digital photogrammetry, to acquire, store, and process, measurable quantities that sufficiently describe spatial and/or physical characteristics of a part of the Earth's surface.

Various applications in GIS, airborne remote sensing, and resource mapping often require data

* Corresponding author. Tel.: +1-905-709-4600 ext. 274; fax: +1-905-709-7153.

E-mail address: MMostafa@applanix.com (M.M.R. Mostafa).

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capture in fully digital form, with sufficient accuracy and in a cost-effective and fast manner. Therefore, integrated digital image acquisition and navigation systems have been developed for such applications (cf. Cramer et al., 1997; Mostafa et al., 1997; Toth and Grejner-Brzezinska, 1998). Such systems are part of a continuing effort which started earlier for the development of GPS-aided inertial navigation systems in support of geomatics applications [see Schwarz et al. (1993) for the mathematical model and proposed applications, and Abdullah (1997), El-Sheimy (1996), Reid et al. (1998), Schwarz (1995), Škaloud et al. (1996) and Toth and Grejner-Brzezinska (1998) for applications].

2. Direct georeferencing model

As shown in Fig. 1, direct georeferencing of digital images can be described by first introducing the collinearity concept rearranged for object coordinates as:

$$r_G^M = r_E^M(t) + s_g \mathbf{R}_c^M r_g^c(t) \quad (1)$$

where r_G^M is the georeferenced 3D vector of coordinates of an arbitrary object point G in the mapping frame (M-frame); $r_E^M(t)$ is the 3D vector of coordinates of the exposure station E, of any imaging sensor, at the instant of exposure, in the M-frame; s_g

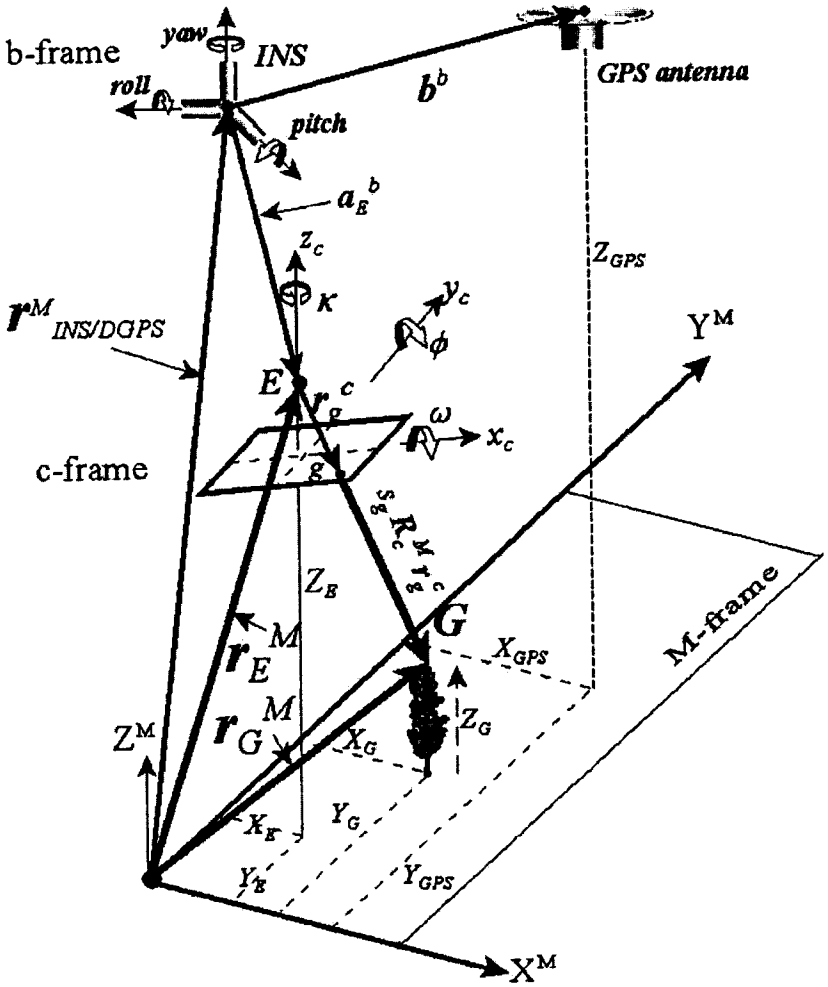


Fig. 1. Elements of direct georeferencing (see explanations in text).

is a scale factor per point per image for each imaging sensor, implicitly derived during the 3D photogrammetric reconstruction of objects using image stereopairs and therefore not explicitly computed in practice; $\mathbf{R}_c^M(t)$ is a matrix rotating each imaging sensor camera frame (c-frame) into the M-frame utilising the three photogrammetric rotation angles ω, φ and κ (cf. Moffit and Mikhail, 1980); and $r_g^c(t)$ is the 3D vector of coordinates of the image point g in the c-frame, expressed by:

$$r_g^c(t) = \left(x_g^c - x_{pp}^c ; \frac{y_g^c - y_{pp}^c}{k} ; -f \right) \quad (2)$$

where x_g^c and y_g^c are the image coordinates of point g corresponding to the object point G; x_{pp}^c and y_{pp}^c are the principal point offsets from the CCD format centre; k is a scale factor accounting for the non-squareness of the CCD pixels; f is the calibrated focal length of the lens in use.

Since the imaging sensor(s), the GPS antenna, and the INS centre do not occupy the same point in 3D space, Eq. (1) can be modified to include the position and orientation offsets which is expressed by the formula:

$$r_G^M = \left(r_{INS/DGPS}^M(t) + \mathbf{R}_b^M(t)\mathbf{a}_E^b \right) + s_g \left(\mathbf{R}_b^M(t)\mathbf{R}_c^b \right) r_g^c(t) \quad (3)$$

where $r_{INS/DGPS}^M(t)$ is the 3D vector of coordinates of the INS centre in the M-frame; $\mathbf{R}_b^M(t)$ is a matrix rotating the INS body frame (b-frame) into the M-frame; a_E^b is an offset vector between the INS centre (b-frame origin) and the imaging sensor exposure station E; b^b is an offset vector between the INS centre and the GPS antenna centre that is measured and compensated for during GPS/INS data post-processing; $\mathbf{R}_c^b$ is a matrix rotating each imaging sensor c-frame into the INS b-frame.

3. Multi-sensor system configuration

The configuration shown in Fig. 2 acquires two separate streams of data, namely, the navigation and

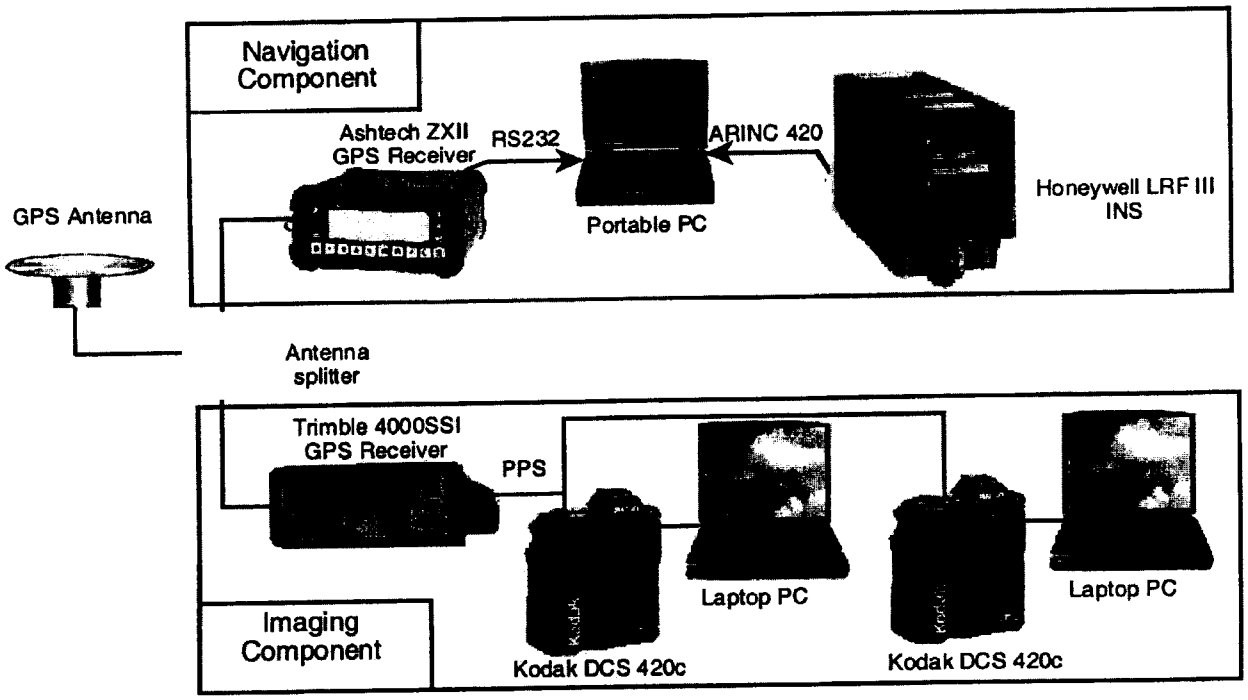


Fig. 2. Hardware configuration.

the imaging data. The navigation data is collected using a Honeywell LRF III inertial navigation system, and an Ashtech ZXII GPS receiver, connected to a portable computer for raw data acquisition and storage for subsequent post-mission processing. The image data is collected by two low-cost Kodak DCS420c digital cameras equipped with a 1.5 × 1 K CCD chip (9 μm pixel resolution). To synchronize the INS, GPS, and image data in a common time frame, the INS records are stamped in real-time by the Ashtech GPS receiver PPS (pulse per second) signal, while a Trimble GPS receiver event marker pulse is used to store the instant of time when an image is captured by one of the cameras. Therefore, all the data are synchronized in the GPS time frame during data logging. The data acquisition is controlled by a real-time data logging software which downloads the GPS/INS/imagery data to the host computers, and time tags the imagery and INS records by the GPS receiver-derived time pulse.

4. Geometric design of a multi-camera system

Several researchers reported on the point positioning accuracy achievable from digital imaging sensors such as the three-line CCD sensors (Cramer et al., 1997), or digital frame cameras (DFCs) (cf. Mostafa et al., 1997). Height determination with the small format cameras is poorer by a factor of three to five compared to horizontal coordinate accuracy (Schwarz et al., 1993; Mostafa et al., 1998). These results were confirmed by simulations. Poor height determination accuracy is due to the poor quality of the 3D space intersection, which can be demonstrated by the intersection (parallax) angle γ between individual camera exposure stations and an arbitrary single ground object, which can be expressed by Eq. (4).

$$\gamma = 2\tan^{-1}\left(\frac{wP_s(1-O)}{2f}\cos\left(\frac{L_{FOV}}{2}\right)\right),$$

$$L_{FOV} = 0^\circ \quad \text{GP at image centre}$$

$$L_{FOV} = 2\tan^{-1}\left(\frac{L_p}{f}\right) \quad \text{GP at image edge} \tag{4}$$

where, w is the image size (in pixels) parallel to flight direction; P_s is the pixel size; O is the overlap percentage between two stereo images; L_{FOV} is the camera lateral field of view angle; and L_p is the lateral location of a ground point (GP) in an image. Note that γ is mainly a function of w, for the same overlap percentage.

Since positioning accuracy depends on the intersection geometry γ (which is dependent on image size), the theoretical accuracy of height determination can be derived by standard error propagation techniques. This yields:

$$\sigma_{Z_G} = \sqrt{2}\,\sigma_{pxl}\frac{(Z_E - Z_G)^2}{2Z_E \cdot f \cdot \tan\left(\frac{\gamma}{2}\right)} \tag{5}$$

where, σ_{Z_G} is the height standard deviation of ground object point G; σ_{pxl} the image measurement precision; and Z_E and Z_G the height of the exposure station and the ground point G, respectively, in the M-frame.

Note that the effect of image position and orientation has been neglected in order to separate and emphasize the effect of intersection geometry. Fig. 3 shows σ_{Z_G} for different intersection angles and different flight altitudes. In Fig. 3, three ranges have been identified. They correspond to $\gamma < 20^\circ$, $20^\circ \le \gamma \le 40^\circ$, and $\gamma > 40^\circ$. The poorest accuracy is achieved in the first range. In the second range, a significant accuracy improvement is obvious, while the accuracy improvement is minimal in the third range. On the other hand, the typical intersection angle for the 1.5 × 1 K cameras used in this system ranges from 3° to 10°. This leads to the lowest theoretical height accuracy. Larger format DFCs can provide better intersection quality. At the time of system development, however, they are more expensive for such a low-cost system and their image acquisition data rate is much poorer than that of the 1.5 × 1 K cameras. Therefore, the imaging component of the system has been designed to include two low-cost 1.5 × 1 K digital cameras, one of which is nadir, and the other is oblique. This allows for covering the same ground scene with a nadir and an oblique image that, when simultaneously processed, provides a wider intersection angle and thus better height accuracy. This concept has been validated through computer simulations, which showed that height determination accuracy is improved by a factor of 3.5 using such a

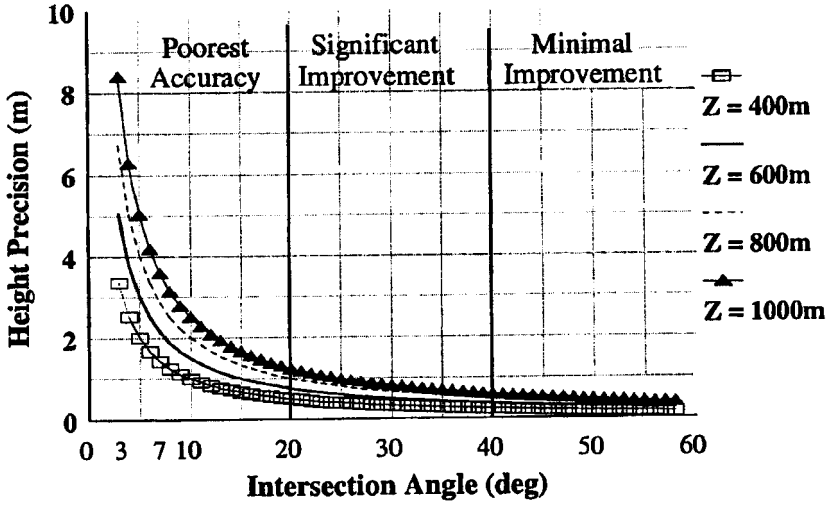


Fig. 3. Height determination precision as a function of the image ray intersection angle.

system. Stereo image matching becomes involved in this case; see Cochran (1995) for a detailed discussion.

5. System calibration

The overall system calibration is required to relate GPS-derived positions, INS-derived attitude parameters, and imagery-derived object point coordinates. Two approaches were followed to calibrate the system. Next, each of these approaches is discussed in some details.

5.1. The terrestrial approach

This approach is implemented in a static terrestrial fashion, where the digital cameras and the INS are tightly coupled using a metal frame, so as to ensure a fixed orientation offset (constant boresight), which is a key assumption in such an approach. The digital cameras are used to acquire a number of images to a precisely surveyed target field, from which their interior geometry, lens distortions, and, for each image, the position of the exposure station and the image rotation angles can be determined (for details, see Mostafa and Schwarz, 1999). The system was set up for 45 min at each station collecting inertial data while an image per camera was captured to the target field. A total of 10 stations was occupied by the system. The 10 images per camera, together with 36 other images per camera that were captured before attaching the cameras to the frame, were introduced to a self-calibrating adjustment software (Lichti and Chapman, 1997), together with approximate orientation angles for each image, and accurate exposure station positions, to resolve for the camera interior geometry, lens distortions, and exterior orientation parameters. The extra 36 images per camera were captured in a configuration that was optimised to strengthen the network for high precision determination of the camera calibration parameters (cf. Fraser, 1997).

The inertial measurements were processed using KINGSPAD in a static mode imposing zero velocities constraint to avoid system position drifts. The calibration procedure was repeated after the test flight using the same approach of data acquisition. Table 1 shows the statistics of the orientation offset (boresight) between the INS b-frame and each camera c-frame in the pitch and roll angles for both nadir and oblique cameras resulting from the pre- and post-flight calibration, respectively. Note that the changes in the angles are within their estimated precision. The azimuth component is, however, of poorer quality than that of the pitch and roll. The precision of each camera yaw angle is about 40″ and 30″ for the pre- and post-flight calibration, while

Table 1
INS/camera relative pitch and roll (°)

Calibration parameter		Min.	Max.	Mean	σ
INS/camera relative pitch					
Pre-flight	INS-Nadir	2.30	2.33	2.312	0.009
	INS-Oblique	29.55	29.60	29.570	0.016
Post-flight	INS-Nadir	2.29	2.34	2.305	0.013
	INS-Oblique	29.56	29.59	29.580	0.009
In-flight	INS-Nadir	2.26	2.35	2.308	0.021
	INS-Oblique	29.53	29.76	29.660	0.045
INS/camera relative roll					
Pre-flight	INS-Nadir	3.11	3.15	3.130	0.010
	INS-Oblique	−1.43	−1.39	−1.410	0.013
Post-flight	INS-Nadir	3.12	3.16	3.140	0.011
	INS-Oblique	−1.41	−1.40	−1.406	0.009
In-flight	INS-Nadir	3.09	3.20	3.147	0.021
	INS-Oblique	−1.53	−1.36	−1.450	0.039

those of the INS are 2.9′ and 3.2′, respectively. The reason for that can be explained by the lack of horizontal accelerations exposed to the system during such static calibration procedure.

The estimated distortion parameters of the lenses used by each camera agreed within their estimated precision for both the pre- and post-flight calibration. For instance, Fig. 4 shows the radial lens distortion profiles estimated during the pre- (solid lines) and post-flight (dashed lines) calibration for the nadir camera and the oblique camera, respectively. The digital camera calibration results agree with a previous work reported by Lichti and Chapman (1997) and Mills et al. (1996), especially for the nadir camera typically equipped with a 28-mm lens.

5.2. The in-flight approach

This approach has been used by Abdullah (1997), Cosandier and Chapman (1995), Mostafa et al. (1997) and Reid et al. (1998). In the case of the multi-camera system presented here, the geometry and imaging configuration differ significantly from those published by the aforementioned authors and, thus, this approach was first studied by simulations and, then, was verified using the test flight data. The general data-flow is shown in Fig. 5.

Due to the poor space resection geometry provided by the digital cameras at hand, the ground control used in the test flight was spatially distributed to strengthen the geometry as indicated in a nadir and an oblique digital images of the test flight shown in Fig. 6. The flight pattern was also designed to help reduce the correlation between the interior and exterior orientation parameters. The image

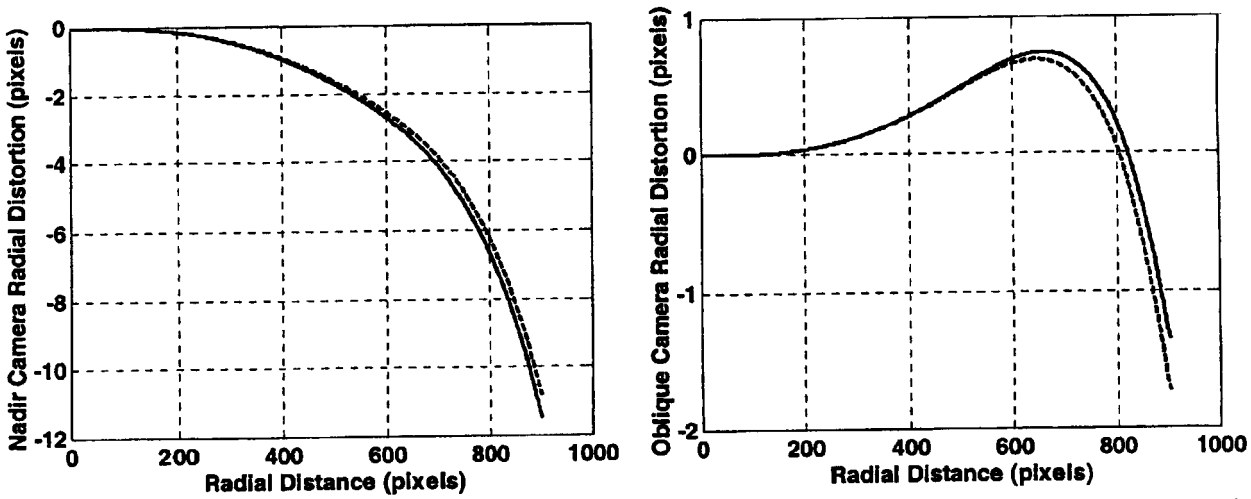


Fig. 4. Lens distortion profiles of the nadir camera (left) using a 28-mm lens and the oblique camera (right) using a 52-mm lens, for pre-flight (solid lines) and post-flight (dashed lines).

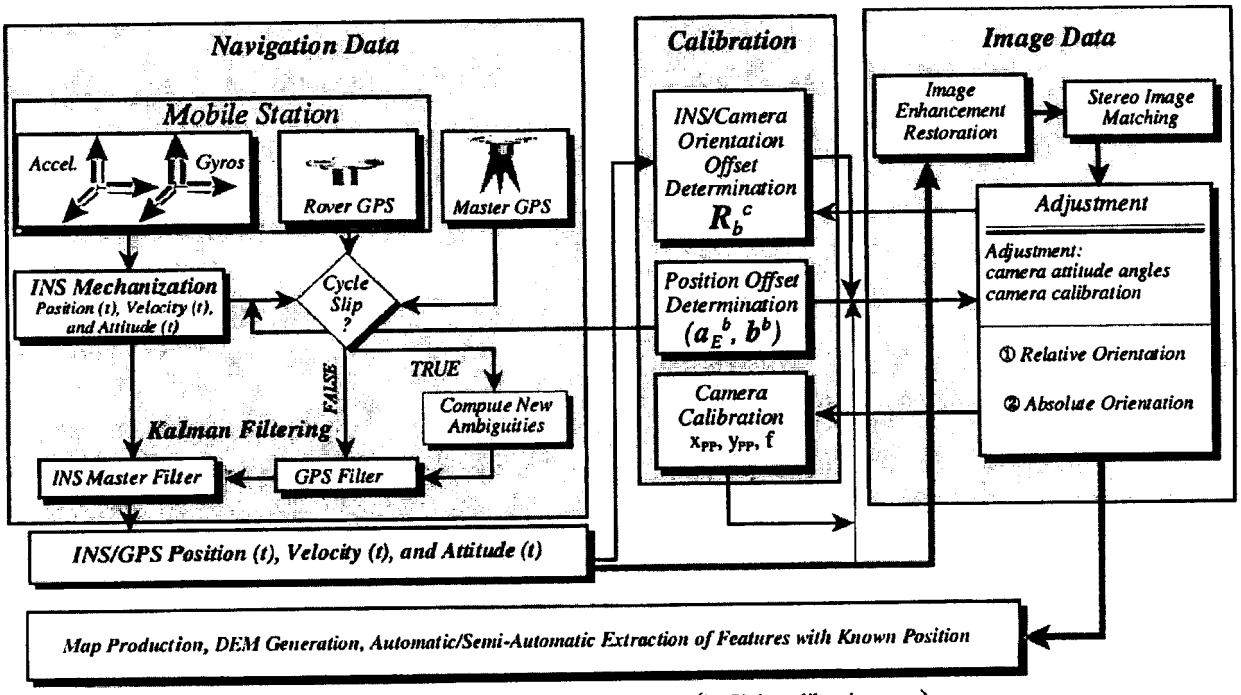


Fig. 5. The multi-sensor system data-flow (in-flight calibration case).

dataset was first processed using GPS-assisted aerotriangulation to decorrelate image exposure station positions from image attitude angles, for better recovery of image attitude angles, to subsequently determine each INS/camera boresight. Table 1 shows the estimated INS/camera roll and pitch offsets for both cameras.

5.3. Terrestrial versus in-flight calibration—a comparison

It is obvious that the terrestrial approach provides a higher precision calibration of the roll and pitch components of the orientation offset. However, it is the opposite in the heading component. The advan-

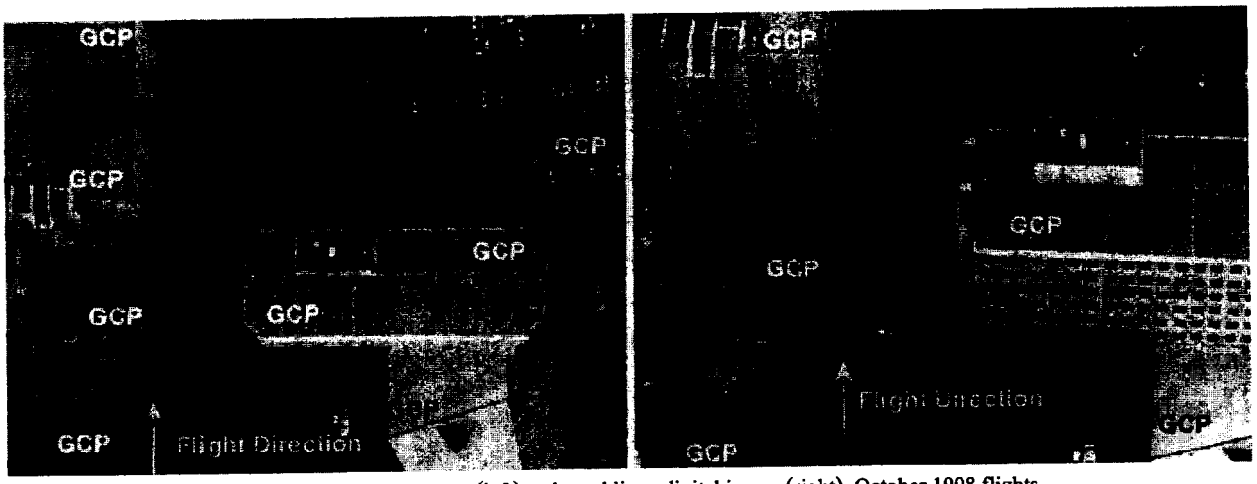


Fig. 6. A nadir digital image (left) and an oblique digital image (right), October 1998 flights.

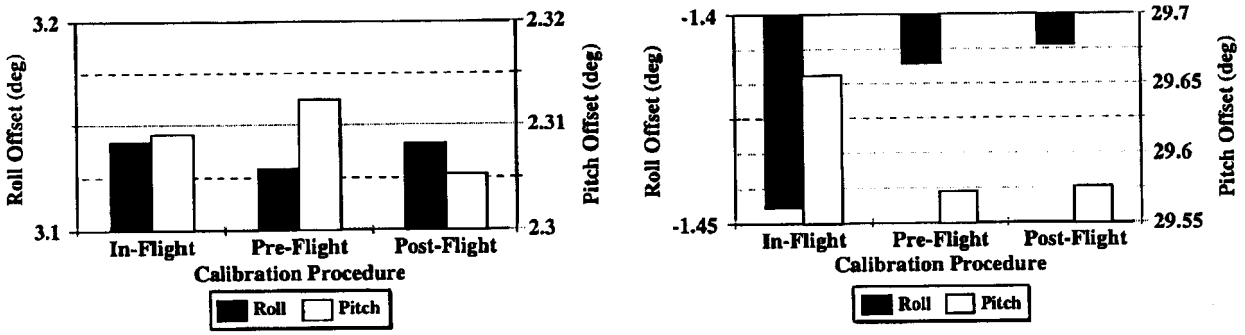


Fig. 7. Boresight roll and pitch components for INS/nadir (left) and INS/oblique (right).

tages of the in-flight approach are: the calibration process and the data acquisition process take place in the same environment; it cancels INS errors developed over time before photography, especially when having horizontal manoeuvres which improve INS-derived heading precision; and it is much more convenient if the system is used with different aircrafts. The drawbacks are: it requires special calibration field, and the calibration accuracy is dependent on the accuracy, density and configuration of the GCP calibration field, the sensor geometry (poorer results for smaller image size) and image point measurement precision.

The advantages of the terrestrial approach are: it provides stronger network geometry for aerotriangulation, higher precision target mensuration in imagery (typically 1/20–1/50 pixel), and is much more controlled than the in-flight approach. The drawbacks are: its geometry is different from that obtained during aerial image acquisition; it is not consistent with the operational environment; the INS-derived azimuth is of poorer quality than that achieved in airborne case; and any error in equipment installation would result in the loss of calibration parameters and the calibration would have to be repeated. Fig. 7 shows the calibrated boresight roll and pitch components for both cameras, while their statistics are listed in Table 1.

6. Multi-sensor system testing in flight

In October 1998, a test flight was conducted over The University of Calgary (U of C) campus for two consecutive days. The campus was chosen because it covers an area of about 150 ha where GCPs could be easily established and because it has a detailed urban character. The hardware configuration described in Section 3 is used in this test flight as shown in Fig. 8. The dual-camera system introduced in Section 4 was used in these flights because it allows a direct comparison between a single-camera system and a dual-camera system. The flight altitude was chosen at 400–500 m, and the flight pattern was designed to cover the entire campus by a block of 50–60% endlap and 30–40% sidelap, using repeated west-to-east flight lines and a single flight per strip in the opposite direction. Two cross strips were also flown from south to north and vice versa. The flight pattern is partially shown in Fig. 9.

Almost 100 GCPs were painted all over the campus. They are needed to provide an independent reference to test the overall system performance when using the airborne data (GPS, INS, and nadir

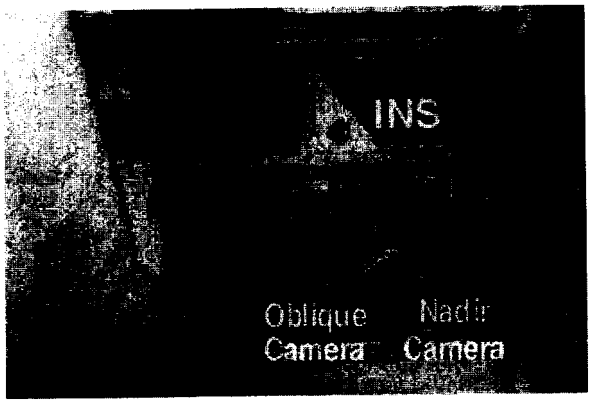


Fig. 8. The multi-sensor system used in the October 1998 test flights.

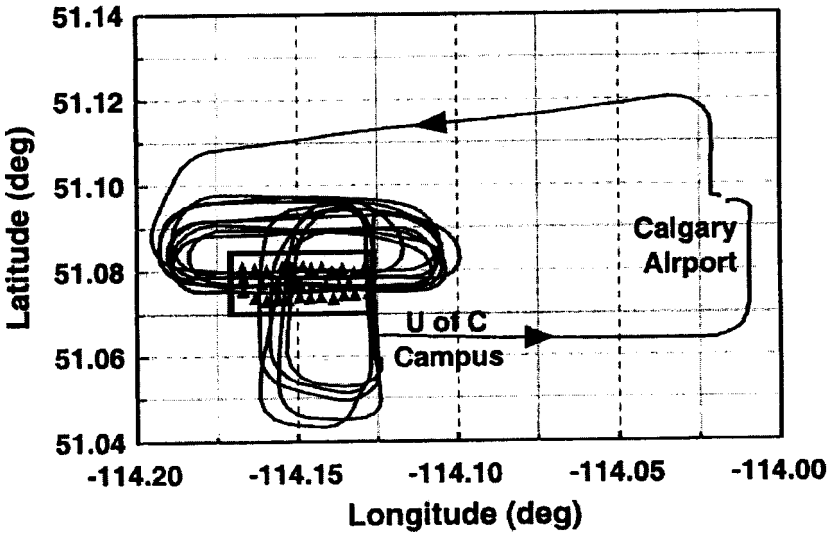


Fig. 9. Partial GPS/INS-derived trajectory of the Calgary test flight.

and oblique images) for positioning objects on the ground. In addition, the in-flight aerial calibration of the entire system, as discussed in Section 5.2, can be tested in this way. Fifty-three percent of the GCPs were placed on roads and parking lots, 27% on medium-height building rooftops, and 20% on highest building rooftops, to end up with a 67-m maximum elevation above the ground. This is to obtain large height differences between adjacent points (e.g., on the ground and on building rooftops) to be able to calibrate the digital cameras and the entire system in-flight, as for example, shown in Fig. 6. All GCPs were surveyed using GPS utilizing multiple master stations. A network adjustment was finally performed to double-check the GPS-fixed baselines. The network adjustment yielded GCP coordinate precision at the level of about 1 cm (1σ) in planimetry and 2.0 cm (1σ) in height.

The flight was done with wide turns to avoid signal blockage by aircraft banking and, thus, the roll angle was typically smaller than 15°. Further, mission planning was done to ensure a good sun angle and good satellite sky distribution. Two master stations were kept running during the test period. One was located close to the airport and was occupied by a Trimble 4000 SSI, the other was on the rooftop of the engineering building and was occupied by an Ashtech Z XII receiver. This resulted in two independent GPS trajectories which, when compared, agreed to be better than 10 cm, which is typical for a 2–8-km baseline. These values indicate that each of the two independent solutions provides sufficiently high-precision camera exposure station position. The Ashtech GPS raw data together with the INS measured specific force and angular velocity raw data were processed using the KINGSPAD software. The Kalman filter-derived estimates of the positioning precision are 0.04, 0.05 and 0.09 m, for latitude, longitude and height, respectively. For attitude, they are 0.0075°, 0.0097° and 0.0152°, for roll, pitch and yaw, respectively.

The GPS/INS interpolated position and attitude angles at each exposure station were used together with the imagery to analyse the system performance when using nadir plus oblique images. After preprocessing the GPS/INS data to compensate for the position and orientation offsets between the navigation and imaging sensors, the compensated position and attitude parameters were used as observable exterior orientation parameters (in M-frame) together with their standard deviations and the image point measurements from the commercial software package PCI OrthoEngine.

The resulting GCP coordinates from processing stereopairs in direct georeferencing mode, or adjusting strips or blocks, were compared to the reference

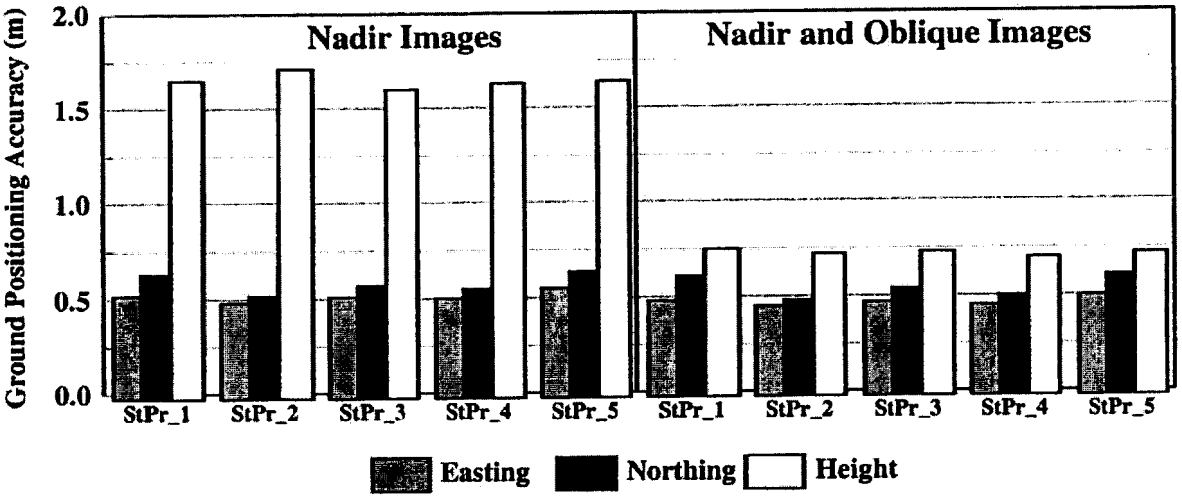


Fig. 10. Positioning accuracy for five stereopairs using nadir images (left) or nadir and oblique images (right).

values on the ground, to analyse both the direct georeferencing approach using stereopairs or GPS/INS-assisted strip or block aerotriangulation. The analysis was done as follows: using a stereopair of nadir images; using a stereopair of nadir images plus an extra oblique image; using a strip of five nadir images; using a strip of five nadir images plus extra oblique images as available; using a block of 3×3 nadir images; and using a block of 3×3 nadir images and oblique images in addition to cross strips in both directions.

Fig. 10 shows the RMS of the differences between the GCP coordinates as determined by GPS/INS/imagery data using direct georeferencing and the GCP determined by the land survey, for five stereopairs (StPr_1 to StPr_5). Each stereopair had four to seven targeted points. Fig. 10 shows the results when using nadir images (left panel) and when using the nadir and oblique images (right panel). From Fig. 10, it is clear that the ground coordinate determination accuracy is consistent in all stereopairs and according to the expectations. The

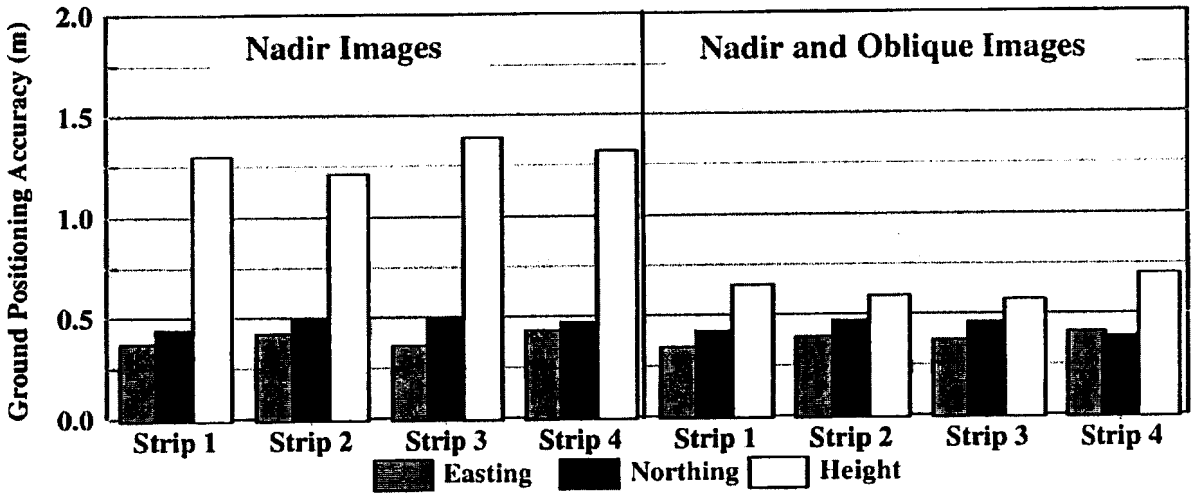


Fig. 11. Positioning accuracy for four strips using nadir (left) and nadir and oblique images (right).

Table 2
Positioning accuracy for nadir and oblique imagery using block configuration

Easting (m)			Northing (m)			Height (m)		
Max.	σ	RMS	Max.	σ	RMS	Max.	σ	RMS
Nadir image block results								
0.69	0.3	0.31	0.71	0.3	0.3	1.93	0.79	0.8
Nadir and oblique and cross strips image block results								
0.54	0.2	0.22	0.61	0.2	0.24	0.86	0.3	0.34

improvement in accuracy due to incorporating the oblique imagery in the processing is minimal in the horizontal components while it is major in the height. The horizontal accuracy improved by only a factor of 1.1. The height accuracy is improved by a factor of about 2.3.

Fig. 11 shows the RMS of the differences between the ground coordinates as determined by GPS/INS/imagery data and the land-surveyed reference coordinates, for four strips. GPS/INS-assisted strip triangulation is used to determine ground point coordinates without the use of ground control. The left panel of Fig. 11 shows the accuracy when using the nadir images only, while the right panel shows the accuracy when using nadir and oblique images. The first three strips were collected in the first day of flight (October 8th) while the fourth strip was collected in the second flight (October 9th) using the same calibrated parameters of the first day. It is clear that the absolute accuracy is consistent between different days of flight.

Table 2 shows the 3D ground positioning accuracy statistics when processing all the available imagery in block mode.

7. Summary and outlook

This paper described the development and testing of an integrated airborne imaging/navigation system for digital mapping. The major research and development component in this project is the integrated system design and software development. The multiple camera system developed here can overcome some of the inherent geometric limitations of small format digital cameras. They are the key to accuracy improvement in such systems. The system performance has been analysed by comparing the ground point positions using GPS/INS/image data without GCP to the land-surveyed coordinates of such points. At an average image scale of 1:12,000, the achievable ground point positioning accuracy in the direct georeferencing mode using stereopairs is 0.5 m in planimetry (1σ) and 1.6 m in height. Adding one extra oblique image to a nadir stereopair improved the height accuracy to 0.7 m. Using GPS/INS-aided single strips of nadir imagery, the system accuracy is 0.4 m in planimetry (1σ) and 1.3 m in height. Adding the available oblique imagery to those image strips resulted in improved height accuracy of 0.6 m. Using GPS/INS-aided block triangulation with the nadir imagery only resulted in ground positioning accuracy of 0.3 m in planimetry (1σ) and 0.8 m in height. Adding available oblique images to the block improved the ground positioning accuracy to 0.2 m in planimetry (1σ) and 0.3 m in height.

Replacing the initial one-camera system by a dual-camera system improved the overall accuracy by factor of 2.3 when using stereopair processing. Using a block of vertical and nadir images and longitudinal and cross strips improved the overall accuracy by a factor of 4.8. Consistently repeatable results were achieved when testing the system in flight over the campus on two different days in October 1998. The internal consistency of the system is higher than the absolute accuracy with respect to reference ground truth. Since system calibration is a major contributor to the overall system error, especially for multi-sensor systems, two approaches have been used, an in-flight approach and a terrestrial one. In the terrestrial calibration, the environment is very well controlled and repeatable, especially for camera calibration. It is well suited to study different factors affecting system accuracy. In the in-flight calibration, the separation of error sources becomes a more complex task; yet it yields more accurate boresight determination. In-flight and terrestrial calibration methods have advantages and disadvantages. The two different methods provide good enough boresight determination for some mapping applications. A comparison between the two approaches needs further tests and detailed discussion, possibly in a future paper.

The system developed here is at the prototype level and, thus, data acquisition was also implemented at the prototype level. For example, the multi-camera system containing two cameras for testing was implemented using two separate laptops and a GPS receiver to synchronise the acquired imagery to the GPS time frame. In addition, the navigation data was collected using a different host computer with a different GPS receiver. Further, a full inertial system and GPS receivers were used to acquire only the raw data from the IMU and the GPS cards. This significantly adds to the system budget and reduces system portability. It is, therefore, recommended to design an industrial computer system that can accommodate the necessary boards for simultaneous navigation and image data acquisition. This would greatly improve system portability and cost. Besides the work presented here, map production using the Kodak DCS series has been reported (cf. Congalton et al., 1998). However, since these cameras are not designed for aerial surveys, the long-term stability of their calibration could be problematic and has to be well studied before using them in mapping.

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Grin, or bare it, for aerial shot Orange County Register (California) February 25, 2001, Sunday

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February 25, 2001, Sunday

SECTION: LOCAL

LENGTH: 570 words

HEADLINE: Grin, or bare it, for aerial shot

BYLINE: By GORDON DILLOW , The Orange County Register

BODY:
The planes! The planes! The Orange County supervisors' eye-in-the- sky snoop planes will be flying over your yard any day now!

And if there's anything out there you don't want the supes or other government officials to take a gander at, you'd better move it or cover it up.

What I'm referring to here is the county's plan to take aerial digital photos of every square foot of Orange County and compile them in a restricted-access computer database. Then, at the touch of a button, various government officials -- police, emergency dispatchers, planning officials, tax assessors and so on -- will be able to call up a detailed three-dimensional image of any street, house, driveway or back yard in the county.

I've been ranting and railing against this $184,000 aerial mapping scheme for months now -- as have many of you. Although proponents say it could be a valuable, even life-saving, governmental tool, I think it's kind of spooky to have a local government agency photographing our back yards -- legal, yes, but still spooky. And in a column earlier this month, I promised to let you know when the photo-planes started flying.

Well, the photography session will begin just as soon as the sun peeks out.

Whenever the next clear day is, we'll be flying," county spokeswoman Diane Thomas told me late Friday afternoon. It could be (today) or it could be next Thursday; it all depends on the weather."

Unfortunately, I can't give you a precise schedule of where in the county the two aerial photography planes will be flying on any given day; that also depends on the weather. One day they may be over Huntington Beach, the next day over San Clemente. It will take them

two to three weeks to shoot the 45,000 digital photos needed.

But they shouldn't be hard to spot: They'll be small, Cessna-type planes flying on straight parallel tracks -- back and forth and back and forth -- at a bout 4,000 feet or lower. If you see one, you are, of course, free to make whatever gesture you feel is appropriate.

What will the aerial photos show? That's open to debate. When it first came up last fall, proponents likened it to looking at your neighbor's house from 50 feet away. Since the public uproar over government intrusiveness, however, they've downplayed the detail.

For example, Brian Fitzpatrick of **Pictometry** International, the New York-based company that's taking the aerial photos, says if you were lying naked in the back yard when the plane flew over, the photos would show a fuzzy image of a person but wouldn't show what sex you are.

Maybe not. But I've seen samples of the photos, and in addition to images of sexless people, they'll show your house, your car, your pool, your patio furniture and that deck you forgot to get a building permit for. They'll also clearly show whatever message you'd like to lay out in 2- or 3-foot-high white letters on your roof or lawn.

If you're unhappy about this, I guess you can call the Board of Supervisors -- the main number is (714) 834-3100 -- although previous barrages of taxpayer complaints haven't done any good. It looks like a done deal.

So keep an eye out. Because tomorrow or the next day or one day very soon, the planes will be coming to take your picture.

And the county government doesn't care if you're smiling or not.

Gordon Dillow may be reached at (714) 796-7953 or via e-mail at gldillow@aol.com.

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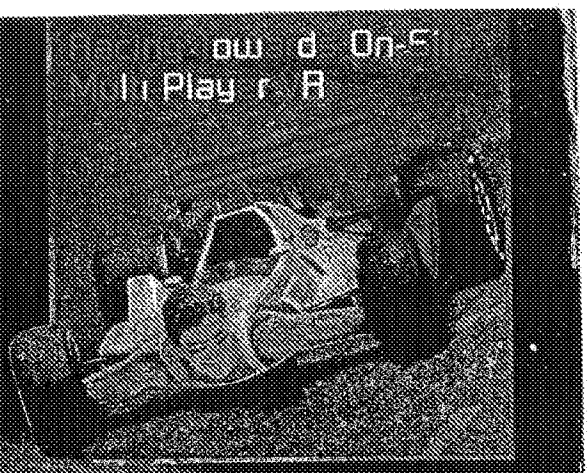
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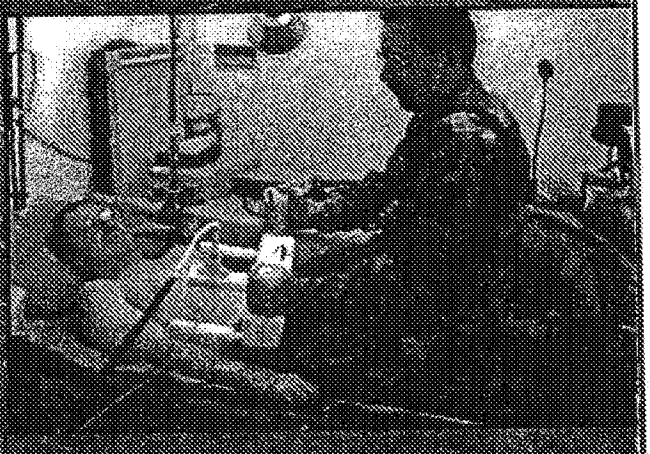


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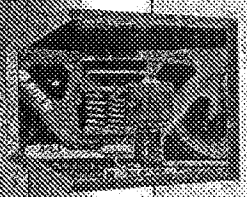


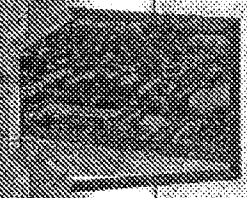


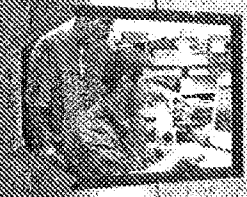
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CONTENTS

ADVANCED IMAGING
JUNE 1997 VOLUME 12, NUMBER 6

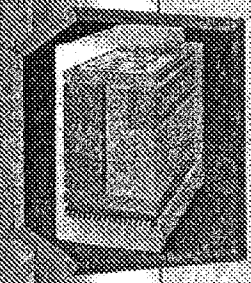






Imaging Solutions 1997

- Introduction: The Contest, The Directory 24
- Industrial Imaging: Machine Vision 26
- Bioscience; Medical Imaging; Scientific Analysis 34
- Interactive Imaging and Communication; Multimedia 40
- Design Graphics; Pre-Press Imaging; Electronic Publishing 44
- Digital/Electronic Photography and Databasing 48
- Remote Sensing/Imaging; Satellite Imaging; GIS 51
- Military and Law Enforcement Imaging; Forensics 54
- Scientific Visualization 57
- Digital Video Production; Special Effects; Animation 59
- Document Imaging; Electronic Image Management 62
- Special Editor's Citation: Imaging in the Classroom 65



The Imaging Situation Now

- **ROI: Image Analysis Software Now** 12
  Capabilities—and bucks. *Len Yencharis*
- **Imaging and the Evolving Macintosh OS** 18
  What's in that Yellow Box—for you? *Carla Ow*
- **Hard Copy: Behind the PhotoDisc Start-Up Success** 66
  Where this imaging firm came from, where it's going. *Charles Reis*
- **Getting Graphic: Real Images for On-Site Entertainment** 86
  Reality that's more than virtual. *Francis Hamit*

The cover *(left/large image)*: The earth and an apparently friendly spacecraft go by, out the window of the new Las Vegas Hilton casino in space"—see page 40. *At right, from top down:* Aerial digital photography that's really coordinated (see page 31); a portable map documents that hit pay dirt (page 42); and medical imaging that's a leader in the field (page 57). Up top, racing toward image-based attractions. (See page 86.)

BPA

Departments

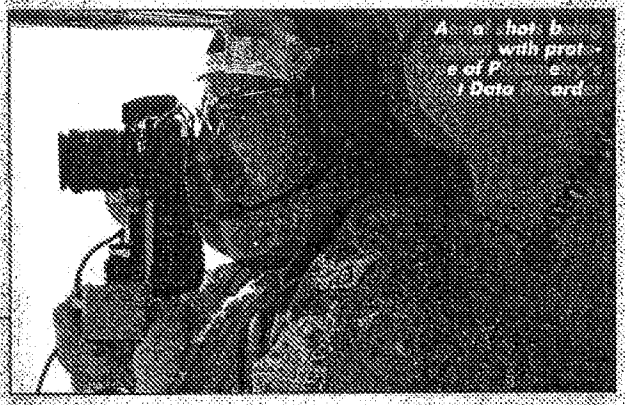
- **Updates:** MMX vision; Space odyssey 8
- **Events:** Oncoming conferences, shows 84
- **Products:** Latest imaging wares of note 71
- **Reaching Those Imaging Solution Suppliers** 78
- **Index of Advertisers** 84

Satellite Imaging/
Remote Sensing/GIS

PHOTONICS IMAGING SOLUTION OF THE YEAR 1997

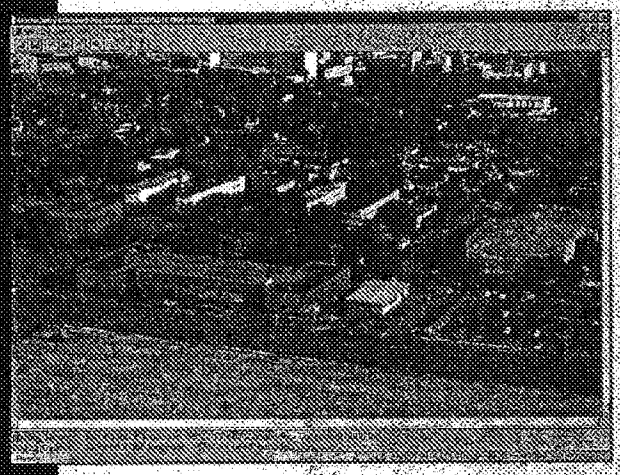
Live Automatic Coordinates For Aerial Images

— The Planning Board; Guaynabo, Puerto Rico



THE CHALLENGE

To create a digital imaging system which can provide accurate geographic coordinates to every pixel in an oblique land image, either from an aircraft or a fixed location such as a building roof. It was necessary for the system to automatically georeference the images and place them in the correct place on the map. Plus, the systems needs to have the data base track all the images containing a selected latitude and longitude.



TOOLS USED

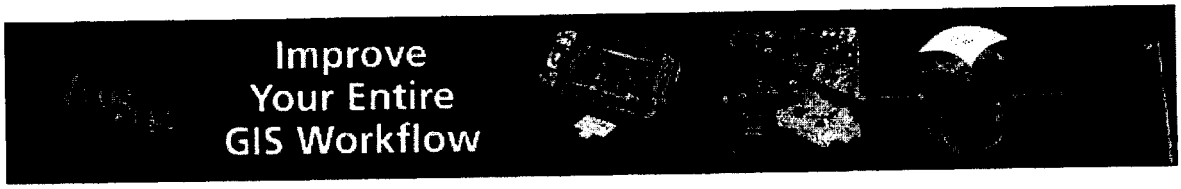
- Kodak DCS 420, DCS 460 Digital Cameras
- AP MC 2000e Digital Camera
- Pictometry Shot Data Recorder
- Pictometry Software Suite (Waypoint Coverage Pre-Planning Software, Coverage Image Capture, Target Image Capture, Reconcile Image Application, Electronic Field Study)
- Adobe PhotoShop
- Adaptec CD-Creator
- Kodak Color Laser Printers
- Compute Platform: C30 Solutions Professional Digital Photography Workstation PDW-200 (Dual Pentium Pro 200, Plextor CD-Recordable Drive, Dual Micropolis 9GB Hard Drives, 256 MB RAM)

THE SOLUTION

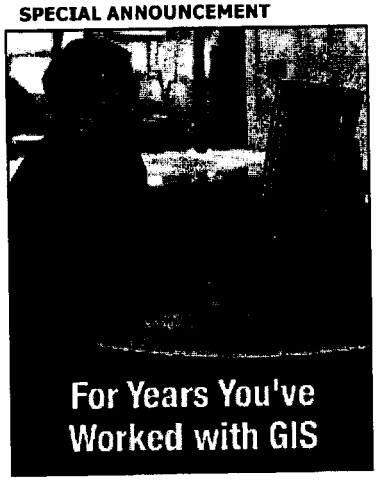
A patented digital land imaging process that automatically and computationally georeferences each pixel of an image, while also locating and accurately measuring all mosaic features, was developed for The Planning Board of the Municipality of Guaynabo, Puerto Rico, by Pictometry Inc. (Rochester NY). This system consists of a Shot Data Recorder developed by Pictometry which attaches to the digital camera and acquires the data needed for georeferencing. Pictometry's software suite consists of Target, which collects specific images; Coverage, which collects images automatically from any aircraft; and Waypoint, which plans the flight path which is depicted on-screen by icons showing the location related to pre-planned course, distance/bearing to the next way point, and the number of images remaining. The Electronic Field Study is another part of the software suite which adds and automatically georeferences images to a mosaic, which contain a digital map of the area. Polygons reflecting the area in the photograph are placed at the appropriate map coordinates. The multiple polygons represent multiple images containing the same coordinates. By clicking on the polygon, available thumbnails are revealed. The user can then select the desired image from the thumbnail at multiple levels of detail. The geographic coordinates for each pixel touched are displayed on the status bar. Any horizontal distances along the ground plane and vertical heights/depressions from the ground plane can be measured just by simple mouse movement. And, for increased accuracy, images can be hand-reconciled.

THE DIFFERENCE IT MADE

The imaging system developed by Pictometry allows anyone to survey millions of square feet of the earth's surface without leaving the office. Since the images are taken at oblique angles (rather than satellite or high-altitude imagery), photo analysis and professional interpretation skills are not needed by the user. Finally, accurate information that was formerly only available through highly technical sources is now available to almost anyone (law enforcement, public planning, insurance, etc.) at a fraction of the cost.



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Pictometry and US Geological Survey Announce - Cooperative Research and Development Agreement.

October 20, 1999

Company: Pictometry International

Rochester, NY -- The United States Geological Survey (USGS) and Pictometry International LLC (Pictometry) announced today a Cooperative Research and Development Agreement (CRADA), which opens a virtual, or "cyber" window on rapidly growing US counties.Users will be able to zoom in and out, on streets, houses and even cars, in their own town, or across the country from their computer at home or work," said Stephen R.Macdonald, Pictometry's Vice President of Business Development.

Under the CRADA, USGS will provide Pictometry with Digital Orthophoto Quadrangles (DOQ's) selected from USGS archives for the fastest growing 400 urban counties across the US. Pictometry will convert the DOQ's from the UTM coordinate system to Latitude/Longitude and recompress the images for use within Pictometry's Electronic Field Study (EFS) client software and Pictometric Image Library server application.Pictometry shall

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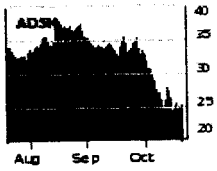
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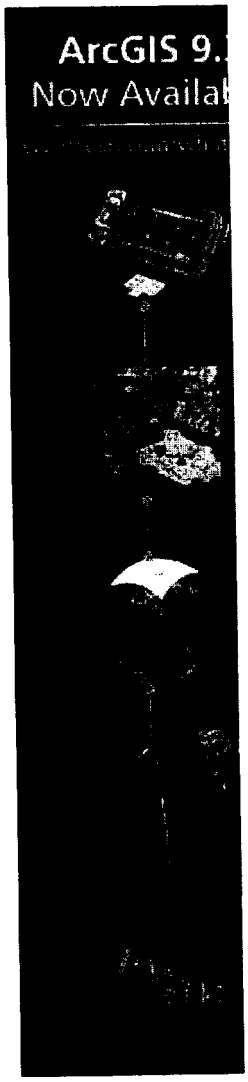
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provide USGS with an Agency wide license for the use of EFS (approximately 10,000 end-user licenses).USGS shall also have access to Pictometry's Image Warehouse (pictometry.com) of high resolution, orthogonal and oblique, color Pictometric Images for internal use.USGS hopes to bolster selected scientific projects with the use of Pictometry, for example studies of the Chesapeake Bay, South Florida, Yellowstone, Middle Rio Grande, Platte River and natural disaster analyses, such as Hurricane Floyd, Irene and others.

"This CRADA will make the DOQ data available to users through a very exciting tool that will provide detailed imagery to a wide variety of applications," said Hedy Rossmeissl, Project Manager for USGS.

USGS also hopes to gain further experience in collecting and using GPS data with high resolution images, and USGS hopes to increase the visibility of USGS's DOQ data by incorporating the data into Pictometry's Electronic Field Study (EFS) client application.Images within EFS are automatically nested within the USGS DOQ's according to their unique spatial coordinates.

The resulting effect allows users to select a specific location and drill down into the image, affording object identification and location with astonishing resolution, clarity and point accuracy.Pictometry is pleased to have this opportunity to share research and development activities with the USGS.In addition to the inclusion of USGS DOQ's into Pictometry's Image Warehouse, Pictometry hopes to broaden the scope of image users beyond map makers, planners, surveyors to include real-estate buyers and sellers, economic development activities, environmental advocates, public safety, business executives, school students and the general public.Stephen R.Macdonald "Pictometry has lowered the cost, risk, delay and removed the rocket science associated with providing extremely high resolution, remote sensed, geo-referenced imagery.It's our goal to standardize the method in which imagery is collected and delivered and in so doing make it extremely affordable.Our strategy only serves to





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complement the goals of USGS!"

Following the granting of its US patent, Pictometry developed revolutionary hardware and software which automatically captures and georeferences digital images from small air craft.The Pictometric images are low cost and contain greater detail than any commercially available imagery.In addition to containing revealing lateral angles, every part of the image reveals its coordinates and measurements between any points in the image.

"It's like taking thousands of field trips from your desk top" said Hedy Rossmeissl, Project Manager for USGS. Instead of waiting weeks, or months for traditional imagery, Pictometry is instantly ready for use in any computer running Windows 95, 98 and NT.

USGS officials were quick to recognize the dramatic enhancements afforded by Pictometry to their traditional Digital Orthophoto Quadrangles (DOQs).The DOQs once inserted in the Pictometry's EFS software provide the "big picture" for orientation which is now linked to the detailed Pictometric images which afford lateral views, horizontal and vertical measurement, annotations which come from or go to other geographic information systems.

The combined products provide powerful new tools and cost savings for public and private land information users who need to share a virtual field trip with information partners.Pictometry has been greeted enthusiastically by County officials concerned with public safety, zoning and property appraisal as well as federal agencies concerned with disaster relief or environmental information.Commercial users such as real estate professionals, insurers and lenders have begun to study the impact of Pictometry on the cost and efficiency of their current land information practices.

Contact:
Stephen R.Macdonald
275 Alexander Street
Rochester, NY 14607
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GCN
Government Computer News

COUNTY LINES

December 2001
By Jason Miller

Software gives small Arlington the big picture

Arlington County, Va., fire chief Edward Plaugher can detail every square mile, building and land feature of the Washington, D.C., suburb, which covers 26 square miles and has a population of 189,000.

Even with such human expertise, the county Fire Department uses a system of digital pictures and metrics software to view its territory. Plaugher said the system helps the fire department respond to emergencies and other calls because dispatchers and firefighters use it to see, in seconds, what a house or building looks like, what is around it and how tall it is.

Arlington County was the first U.S. county to install the Pictometry Information System and Electronic Field Study, both from Pictometry International Corp. of Rochester, N.Y. The system came in especially handy Sept. 11, when a hijacked jet crashed into the Pentagon—in Arlington County.

Soon after the crash, county workers pulled up pictures of the structure. The software measured the area of the crash and provided county authorities, the FBI and military police with as many as 12 views of the building.

"We could count the windows and figure out how large the blast damage was," Plaugher said. "We can plot ... exact measurements of the critical components of the incident scene and then pass the information to the other authorities."

Plaugher said federal authorities were given printouts of Pentagon pictures so they could orient themselves within the large area of land.

The system, which cost the county $14,000, runs on a 1-GHz Pentium III notebook PC from WinBook Computer Corp. of Hillard, Ohio. The notebook has 256M of RAM and a 20G hard drive.

The system runs on Microsoft Windows operating systems and can be used with most geographic information systems software, said Dick Kaplan, the company president and CEO.

Pictometry provided digitized aerial photographs of the county in square mile sections from three directions: straight down, 40 degree side angles from north to south and from east to west. Pictometry then divided the county into 49 subsectors of 750 square feet and created nine more oblique angle pictures.

The county stored the images and through the Electronic Field Study software measured the distance between two points, the radius of a section and other features.

Arlington County's images take up 9G of storage. Larger counties might need anywhere from 60G to a terabyte of space, Kaplan said.

"Before this system, we had to measure the distances by hand," Plaugher said. "This gives us a pretty

wonderful operational capability."

The department shared the data with the county police, public works, parks and recreation, and environmental services departments.

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LAW ENFORCEMENT

Pictometry: aerial photography on steroids

When a call comes into a 911 center from a call phone, an approximate location can be determined. However, that location might be as much as 100 yards away. What if a dispatcher could pull up straight-down or oblique views of the area and while talking to the caller pinpoint the exact location of the call right down to the street corner from which the citizen was calling?

With a new system from Pictometry International Corp. of Rochester, New York, this is entirely possible. Pictometry is a visual intelligence system that uses aerial photography to capture, process and analyze orthogonal (straight down) and oblique (taken from angles) images to create aerial "maps" of a given area in 3D.

This method of gathering images allows users to view and analyze any house, building, intersection, fire hydrant, tree or other physical feature in a given area. The advantage of this becomes clear in the above scenario where the dispatcher would use Pictometry's Electronic Field Study ™ (EFS) software to view actual imagery of the area where the call was originating from to pinpoint the caller's exact location. This information could be passed on to first responders dispatched to assist the caller.

"Public Safety can see where that person is without having to guess that the individual is within 100 years or meters of where that cell phone is telling them the caller is," says Lou Oshier, director of law enforcement communications in Erie County, New York. "Today, if they pull up a map they get a 2D map. With this software, they see actual imagery of where the person is located [in 3D]." Oshier points out that Erie County is in the process of implementing this technology, which he dubs as either Phase 1.5 or 2.5, depending on what level of compliance the PSAP is in. Dan Pennacchia, Pictometry's senior vice president of sales and marketing says, "With Pictometry's newly formed partnerships and applications with Plant Equipment, Inc., Tiburon Inc. and Brite Computers, 911 call-takers will be able to see an actual picture of where the person is calling from within seconds and dispatchers will be able to send those coordinates to public safety computers in mobile vehicles within seconds." Pennacchia says, "Pictometry is going to develop additional partnerships and applications with other companies that perform similar solutions where necessary."

After a terrorism incident or natural disaster, this capability has many applications. It can be used for planning purposes to help first responders plan perimeters, roadblocks, evacuations, etc. In fact, Pictometry was used in Arlington, VA after 9-11, because the company had already gathered imagery for the Pentagon (see images). Arlington Fire Department officials used Pictometry images of the Pentagon taken before the crash to plan their response after the disaster. "We used the software to measure the area of the crash and the extent of the damage, and provided county authorities with as many as 12 views of the building," says John Snyder, Arlington County Fire Department management specialist.

"In any immediate situation, you can be looking at the imagery, plan around the imagery and coordinate that information in terms of what fire, police, EMS or other groups need to know about or do around the disaster area," Snyder says. "This helps users every single day by providing them with a visual view of where they are going before they get there."

What Is Pictometry?

Unlike satellite image photography, which only allows the tops of buildings to be photographed, Pictometry, which was introduced by the company about two years ago, is able to capture every feature in its entirety. This is possible because in addition to using the orthogonal images captured in traditional aerial photography, up to 80 percent of Pictometry's images are oblique, or taken from angles, allowing users to see a complete view of every feature in a given area. So, instead of just seeing the tops of buildings, users see the sides of these buildings right down to street level.

Pictometry International Corp. captures these images with a camera-equipped Cessna 172 light aircraft; an aircraft chosen for its flexibility and its ability to fly down low. It takes the company anywhere from 10 to 60 days to gather the images, depending on the size of the county and other conditions such as weather. Most pictures are taken when the leaves are off the trees and there isn't snow on the ground. Images are also not gathered when it's rainy.

When gathering images, the company breaks the county to be photographed into square mile sectors. Each sector is called a community sector. Crews begin capturing imagery in each sector from three views: straight down and from 40-degree oblique angles i.e., one from the north to south and one from east to west. "In a sector that has any kind of development [residential, commercial, industrial, hospitals, schools, road systems, etc.], we come down very low and take that one square mile and break it into 49 sub-sectors [or neighborhoods]. Each one of these is approximately 750 feet square in size," says Dick Kaplan, President and CEO, Pictometry International Corp. Each 750-foot-square neighborhood is captured from two opposing views (one from east to west and the other from west to east). "When we are done, we literally have every square foot of the county captured from up to 12 different views," Kaplan says.

The company then catalogues these full-color digital images, which are updates every two years, into software libraries called Electronic Field Study, or EFS, that are arranged by county for use by law enforcement, fire departments, EMS agencies, public works and other municipal departments. "Anyone who needs geographic referencing, planning or measuring ability can benefit from these images," says Kaplan.

Using the images

These high-resolution images, combined with EFS, which enables zoom, measurement, location and annotation - make Pictometry an in dispensable tool for first responders. Emergency teams can coordinate and communicate much more effectively when they are all viewing the targeted areas from multiple angles, using the same images and data sets, whether in the command center of in the field. A tour of an area can be made from the desktop with a bird's eye view, allowing agencies to save time and respond more accurately.

Once in EFS, the images can be accessed in two ways. One, the user can access them by entering an address. All the pictures of that address will instantly come up as thumbnail images on the side of the screen. The other way is to go to a map and simply click on the area you wish to view. To view in more detail, the user double clicks on the thumbnail images that pop up.

Once the user has pulled up a full-screen image, the software offers a number of tools that can be used to enhance the view. One is the distance tool, which allows the user to measure things contained within the image. For example, firefighters could measure the distance from fire hydrants in the area to the inflamed house while en route to a call to determine the length of the hoses they will need. By drawing a line around a parcel where a hostage situation is taking place, for instance, law enforcement officers could learn the square footage of the area and pre-plan how they will arrive at the scene.

Scott Hill, the company's senior vice president of operations, recalls surveillance, that he was part of as a captain with the Rochester (New York) Police Department, where this technology would have come in handy. A narcotics squad brought a ladder to help monitor drug activity from a vacant building. It was too short. "With this technology, they could have measured and known exactly how much ladder was needed," Kaplan says.

The software's location tool allows users to click on any point in the image and receive coordinates for that point. There's also a bearing tool that enables users to draw a line down

a road, for example, and learn how many degrees from north the line is traveling. If there's a fork in the road, users can utilize this tool to measure that angle. Measuring angles in this way might prove beneficial in a surveillance operation. For instance, in a surveillance of three houses, the tool might help law enforcement determine what lens to place on the camera to enable it to capture all three houses in a single view.

One of the most important tools, says Kaplan, is the annotation tool. This tool enables users to attach unlimited amounts of information to an image. To track crimes, this would eliminate having a map on the wall with pushpins stuck in it. Officers could actually pit a dot on the Pictometry images in every place that a crime had occurred. Then when an officer clicks on a specific for in an image, information on every crime that took place at that location would pop up.

"If there were a series of burglaries in an area, you could actually highlight those houses [within EFS], show what kind of burglary it was, and from there start to see some patterns," Hill adds.

Likewise, agencies could attach a list of hazardous materials stored in a building to its Pictometry image. So if there's a fire at a specific site, firefighters can click on an image of the building and learn about the hazardous materials stored within it, the name of the building's owner, and where they can gain access to the facility. In addition, they can click on neighboring facilities to learn if hazardous materials are being stored in other buildings adjacent to the fire. This information would allow incident command to coordinate the services of all first responders. Firefighters would know what hazards exist within the building; EMS would be aware of the hazards rescuers might come in contact with and how to treat them; and law enforcement would know the type of perimeter that needed to be set up around the affected area.

Other information attached to the images might include floor plans; interior images; streaming video; crime scene evidence; and directions or other text information for in-field procedures such as setting up perimeters, access and egress routes, and staging areas.

"Supervisors or command staff have the responsibility for what goes on in an emergency response," says Hill. "They really need to know what goes on and in great detail. Pictometry provides them with the information they need."

Too much info?

Due to Pictometry's ability to capture close, detailed pictures of a geographical area, the issue of privacy has come up. Currently, Pictometry is being used in Orange County, California, where according to an article in the "Orange County Los Angeles Times," resident are concerned that these photographs and software technology will infringe on their privacy through the software's image enhancing features that allow users to zoom in on an area or object.

Such privacy concerns are really without merit, Kaplan points out. "We can zoom in to the extent that we can make out a car and the model of a car, but we can't zoom in to the point where you see faces or the number plates," he says. "The images are static and we can't tell identities of the people, homes of vehicles in them."

The benefits of this technology are that it allows public safety professionals to view the physical layout of the area on a computer screen long before they arrive at the scene. This lets them begin reviewing ways to resolve potential problems en route to the call.

"Because you have all this information and so much more on the image, you know the staging areas for emergency situations. You can look for parking lots for emergency vehicles or helicopter landing areas. You could even get the geographic coordinates for the helicopter," Hill says.

Having access to Pictometry information saves time, and emergency response situations, seconds can mean the difference between success or failure, and even life and death.

< Back to the News Room home page.

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FOCUS - 11 of 41 DOCUMENTS

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The Post-Standard
The Post-Standard (Syracuse, NY)

May 18, 2002 Saturday Final Edition

SECTION: LOCAL; Pg. B1

LENGTH: 795 words

HEADLINE: COUNTY GETS AN EYEFUL AERIAL, DIGITAL IMAGES SHOW STREETS, TREES - AND BACK YARDS

BYLINE: Teri Weaver Staff writer

BODY:

Picture this: A town code enforcement officer wants to know whether a couple has put a deck on the back of their house. The officer could drive by the house, but the view of the back yard is blocked.

So the officer, instead, turns to a computer and with a few mouse clicks has a color image of the back yard so detailed that the number of trees planted along the property's border is clear.

Welcome to Pictometry, a company that blends computer software with aerial and digital photography to create a picture record of all the streets, buildings, houses, street lights and utility poles in a given area. The Rochester-based company has photographed many of the counties along the Thruway, some cities in California and all of Massachusetts.

Last September, it was one of two companies hired to take aerial pictures of what was left of the World Trade Center towers. Pictometry did the same in Arlington, Va., at the Pentagon.

Now, Onondaga County officials will have this service at their fingertips. The county has agreed to pay $88,000 for a two-year contract with Pictometry.

In the next few weeks, Pictometry plans to make the final delivery of computer software program that contains color and three-dimensional shots of every inch of the county's 780 square miles.

"You get the sides of buildings," said Karen Kitney, the director of the Syracuse and Onondaga County Planning Agency. "You can get a lot of details from the ground. You can measure on screen. You can e-mail a photo to an economic development client."

The county's planning, transportation, economic development and emergency communications offices already are making use of the new system. The county can pass along all the information to the towns and villages - free of charge. That means each town assessor and each village code enforcement officer can readily use the software.

The county already keeps aerial shots on file of all properties within the county. But the shots are black and white, and they are stored in filing cabinets at SOCPA on the 11th floor of the Civic Center. Putting the information on

computer makes it immediately accessible - and easier to analyze - for dozens of government workers.

At the 911 center, for example, director Stephen Wisely plans to load the photos of major intersections on the personal computers that dispatchers use.

"We'll be able to pick out where the accident is," Wisely said.

In addition, the software program that manipulates the data gives users more options. The computer system can measure a building, determine the acreage for an area or give the coordinates of a specific spot of land, according to Richard Kaplan, Pictometry president.

"We capture every square foot of the county," Kaplan said this week. "Then, within 15 seconds, you can look at up to 12 different views of the same building."

The easy access to people's front and back doors, windows and driveways has led to some claims of invasions of privacy.

Two years ago, supervisors in Orange County, Calif., spent $184,000 to have Pictometry photograph and create a pictorial library of the county. But when the supervisors tried to recoup the money by selling the images on the county's Web site at $15 to $25 apiece, hundreds of residents complained. The supervisors eventually backed down, according to the Orange County Register, and kept the images for government-use only.

Onondaga County officials have yet to decide how to handle the privacy issue. For now, they plan to make the images available for government use and set a policy for selling the images in the coming weeks. The county will not own the images, but will lease them from Pictometry for two years. The county must give Pictometry a share of any money made from selling the pictures.

Dan Pennacchia, who heads the company's sales and marketing department, said the pictures do show the number of doors and windows on a building. They are not detailed enough, however, to see through a window, read a license plate or see the face of a person, he said.

"There's no ability to identify anyone," he said.

The pictures are shot at 40-degree angles at 2,000 feet and again at about 4,000 feet, Pennachhia said. They are shot during the spring and fall, when there is no snow on the ground or leaves on the trees, Kaplan said. The cameras are mounted on a 172 Cessna and can take as many as 10,000 images a day.

"It's basically like mowing the sky," said Tim Dec, a sales manager with Pictometry who lives in Baldwinsville.

Pictometry said the county program should be ready by June. Soon after, county officials will deliver copies to town and village offices.

"The assessors are really anxious to look at it," said Don Jordan, who works in county planning.

GRAPHIC: PHOTO; Stephen D. Cannerelli/Staff photographer; DON JORDAN looks at aerial images on a computer terminal last week at; the Syracuse Onondaga County Planning Agency. Jordan manages the; agency's Geographic Information Systems Program. At his left is a; large print of a digital image of Oneida Shores County Park. The; images are from computer software purchased from Pictometry.; Map/ Photos; Photos courtesy of Pictometry International Corp.; AERIAL PHOTOS GET DOWN TO EARTH; Onondaga County has agreed to pay $88,000 for a two-year contract with; Pictometry International Corp. for a computer software program that; contains color and three-dimensional photos of every inch of the; county's 780 square miles. The county's planning, transportation,; economic development and emergency communications offices already are; making use of the new system, and the

county can pass along all the; information to towns and villages free of charge. That means each town; assessor and each village code enforcement officer can readily use the; software. Here are examples of the kinds of detail the photos can; provide to local officials. The map above shows the approximate areas; in the photos. The colored boxes correspond to the rules around the; photos and color key with the captions; the arrows indicate the tops; of the photos.Color.;

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Firm gets latitude to map O.C. in 3-D;GOVERNMENT: Supervisors see uses for the detailed photos, but do they invade privacy? Orange County Register (California) September 22, 2000 Friday

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September 22, 2000 Friday MORNING EDITION

SECTION: NEWS; Pg. A01

LENGTH: 779 words

HEADLINE: Firm gets latitude to map O.C. in 3-D;
GOVERNMENT: Supervisors see uses for the detailed photos, but do they invade privacy?

BYLINE: CHRIS REED , The Orange County Register

BODY:
The county government will soon have at its disposal a digital database containing three-dimensional images of every square foot of Orange County -- a prospect that delights law enforcement, planning and public-works officials and alarms a privacy watchdog.

The high-resolution photographs of everything from backyard patios to the infield at Edison International Field also will be available to the public for a fee.

On Tuesday, the Board of Supervisors approved the unprecedented initiative. Without discussion, members ratified a $ 183,952 contract with **Pictometry** International, which expects to survey the county with its aerial-mapping technology in February and turn over the image database by June.

The founders of the upstart Rochester, N.Y., firm patented the mapping system in 1996 and have spent the past four years fine-tuning it and developing commercial applications.

Orange County is one of the first governmental bodies in the nation to sign up for **Pictometry's** services. Company officials say given their system's low cost and utility, they expect it to be in near-universal use by local governments within a few years.

"We haven't made a presentation yet to a county that says they

don't want it," said Brian Fitzpatrick, **Pictometry's** West Coast general manager.

Orange County's contract allows the county to resell the database to cities and other local government agencies and use the proceeds to recoup its costs. The deal also allows the county to sell individual images to private customers, with **Pictometry** receiving a royalty of 30 percent to 40 percent.

The county's Planning and Development Services Department plans to develop an Internet site where individual images from the February mapping can be bought for $ 15 to $ 25.

The county plans to bring **Pictometry** back every two years to update the image database.

The images go beyond ordinary aerial imaging -- the plain, straight-down satellite photos that long have been available.

Instead, the company puts cameras in slow-moving, low-flying planes to build up a vast information bank of oblique (taken-from-an-angle) images.

The result: A user of the technology can tap a few keys on his PC -- a street address, tax ID, latitude and longitude, eventually perhaps just a phone number -- and immediately view a business or home from many angles.

"The images are extremely sharp," said Fitzpatrick, comparable to "looking from 50 feet away at your neighbor's home. "

"It's quite incredible," said sheriff's Capt. Dan Wilkerson.

"You can literally look down streets and see what's there. "

Wilkerson said the **Pictometry** database will prove invaluable to deputies involved in pursuits and emergency rescues, preparing for drug raids, dealing with hostage crises and in virtually any situation in which officers are unfamiliar with the lay of the land.

District Attorney Tony Rackauckas called it a great tool for gathering evidence.

County technology czar Leo Crawford said public-works and planning officials will be able to use **Pictometry** to take "digital field trips," using the database to evaluate community needs, measure parcels or buildings and check on hazardous conditions.

Fitzpatrick said it also could help environmental regulators assess water runoff and pollution and assist tax assessors in determining the value of property.

But an official with the Privacy Rights Clearinghouse said Orange County appears to have embraced a far-reaching technological innovation without considering all the implications.

Jodie Beebe of the San Diego-based privacy watchdog group said there was no question that the **Pictometry** technology was legal.

"You do have an expectation of privacy within the home," she said.

"Outside the home, that's fair game. "
But even if the technology is legal, Beebe said, it's still troubling.

The detailed images could be purchased by potential burglars and stalkers seeking entry to buildings, she suggested.

Telemarketers eager to sell aluminum siding or other home products might survey subdivisions to get lists of potential clients.

"Information is always a double-edged sword," Beebe said. "I don't think they've thought this out. "
Crawford, however, said county officials never saw the **Pictometry** technology as raising any privacy issues.

And the retired aerospace engineer who's now the county's top elected official seemed more in awe of the new technology than wary.

"It's pretty remarkable," said Board of Supervisors Chairman Charles V. Smith. "I got very excited about it very quickly. "

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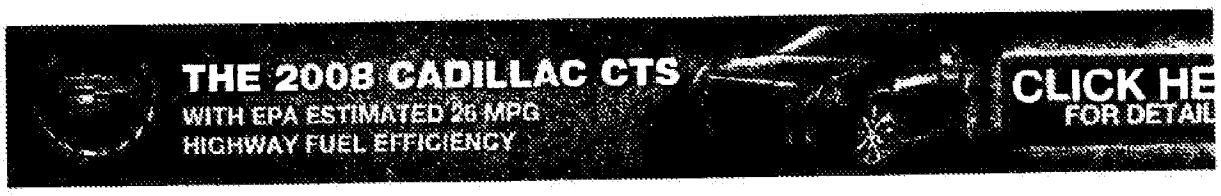
GRAPHIC: ILLUSTRATION; COLOR PHOTO; EYE IN THE SKY; Orange County soon will have photos of every building in the county as crisp as this shot of a home in Pittsford, N.Y. Users of the image database can zoom in to the point where even traffic signs are easy to read, according to **Pictometry** International officials. (A01) (**Pictometry**); Illustrations; A digital camera will sanpe images while the plane is flying at about 120 mph.; Levels of detail. Users can click on any point on the map and view images of the area. See hard copy or graphics file for illustrations. (Graphics reporting by Haeyoun Park) (Turney)

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Archive for Monday, October 16, 2000

Orange County Freezes Ambitious Aerial Photography Project

By David Reyes
October 16, 2000 *in print edition B-1*

It was an easy sell: Cops, firefighters and county planners zipping down streets and across backyards with a simple click of the mouse.

From Disneyland's Matterhorn to the sluggish El Toro Y, the notion of photographing every square mile of Orange County with high-resolution aerial images was eagerly embraced by county leaders.

They even endorsed the concept that they could recoup the cost of the aerial mission by selling photos of neighborhoods, cul-de-sacs and industrial complexes on the Internet.

But then reality knocked.

Hundreds of residents phoned and e-mailed the county, complaining that the ambitious photo shoot smacked of Big Brother on some sort of paparazzi romp through the backyards of about 2.7 million county residents.

"We dropped the ball on this issue when we approved it," conceded Supervisor Todd Spitzer. "There were questions I should have asked and failed to."

Indeed, the entire two-year, $184,000 aerial shoot is now on hold while the county reviews privacy and legal issues. At issue is whether the county should contract with Rochester, N.Y.-based Pictometry International LLC, and if so, should the pictures be hawked for $15 to $25 on the county's Web site?

Elizabeth Schroeder, associate director of the ACLU of Southern California, says county bureaucrats were too eager to snatch the latest in high-tech tools without weighing the social downside, such as loss of basic privacy.

"I found it rather shocking that they can have technology that can go under the eaves and in your backyards," said Schroeder. "And if you can sell this information to private parties, you can easily sell it to burglars.

"All of us have things in our backyard that we don't want anyone else to see."

Supervisors acknowledged they weren't ready for the hundreds of phones calls and e-mails that poured in after the board unanimously approved the project Sept. 19.

What makes Pictometry different from scores of other aerial products is that, rather than being taken from directly overhead, pictures are taken at an angle that–once combined with the company's software–allows users to zoom in on neighborhoods and measure the height, width and length of any feature in an image, including gullies, buildings, trees, poles and roads.

Under terms of the contract, the company would take 60,000 photographs of the county from an airplane flying at about 4,000 feet. The images would be stored in a county database and sold to cities and governmental agencies, including police and fire departments.

Though supervisors were assured the project had been fully researched by county staff, Supervisor Jim Silva said it's evident that questions on privacy rights, public access on the Internet and the county's liability "still need to be addressed."

Board Chairman Chuck Smith, a retired civil engineer, said he continues to believe in the concept and thinks it will be a money saver for county workers who deal with zoning and planning matters.

"We've asked for a legal review, and although we've given the go-ahead to do it, [the board] can limit it from being distributed on the Internet," Smith said.

For planning purposes, the aerial imagery is perfect, said Brian F. Fitzpatrick, West Coast general manager for Pictometry. Rather than having a developer show an artist's rendering of a new shopping plaza, the digital software allows a planner to test the developer's claims by immediately seeing what the site will look like, he said.

Police officers would have the ability to view structures and barriers to tactical threats on a computer screen in a dispatcher's office, in essence looking an area over until police get to the scene, said Sheriff's Capt. Ron Wilkerson, who viewed a product demonstration.

"It's an interim measure until a helicopter arrives," he said. "The resolution, I thought, was outstanding, and at least it allows us to have something that we can bring up [on a screen] to get an idea of the physical layout."

As to the concern with privacy issues, Fitzpatrick is matter-of-fact. "There is no law that says you can't take an aerial picture or sell it."

The county spent months reviewing the company and its products, said county officials who sent a two-person research team to New York last spring. In addition, officials said, a survey of 1,200 residents did not reveal any distaste for selling the photographs on the Internet.

Vicki Stewart, manager for fiscal programs services, said the survey showed that 70% thought it was a great idea, 26% were neutral on the matter, and only 4% didn't like the idea.

Stewart said she understood why residents would be sensitive to a proposal involving high-tech cameras but suggested that, unlike satellite imagery as portrayed in Hollywood movies, "this is one shot in time and it gets upgraded every two years."

But Leo Crawford, the county's chief information officer, scoffed at allegations that aerial imaging gives

viewers some special photographic ability to peek in windows and under bushes. "That's laughable," Crawford said. "The quality is just not there. You could probably tell if an individual is standing there, but it's too fuzzy to note much else."

Officials in Onondaga County in upstate New York, where Pictometry products are in use, said none of the county's 468,000 residents has complained about an invasion of privacy.

"There are tons of towns and villages around here that will be able to use it for real property tax assessment work, and we might make it available to help site development in planning," said Martin Ferrell, Onondaga's communications director. "It's a good way for people to look at the potential building site and deal with issues like wetlands and whether there's rail service."

But what resonates among county residents isn't what the product can do or the number of bells and whistles, but their privacy and who will have access to the photographs.

"I'm no attorney, but it looks like this could be used by law enforcement to do a property search without the owner's permission, a warrant or probable cause," said Richard Lubline, an Aliso Viejo resident.

Recent Supreme Court rulings have held that aerial photographs are a "legitimate exercise" of the investigatory powers of government, said Tony Arnold, associate professor at Chapman University Law School.

"It seems to me that this is one of the areas that will be coming increasingly before the courts," he said. "The [courts] may impose limits, for example, if it's a swimming pool and heights of buildings–that might be reasonable. But if it captures a lot of detail and aspects of the property typically hidden from view of the public, it may cross that line in the realm of privacy."

But county supervisors have a more practical problem, Arnold said.

"Basically, people don't like people intruding in their privacy, which is maybe even more problematic for the county than the legal issues, especially in Orange County, which has a particular sense of privacy."

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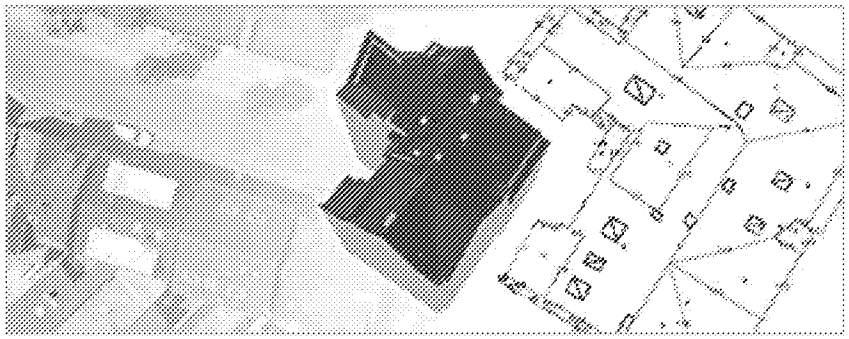
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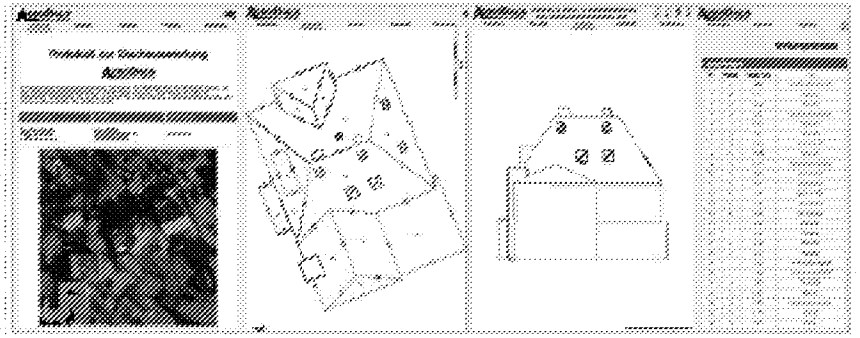
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