Modern Photogrammetry

Ray Hintz, PLS
Univ. of Maine
ray.hintz@maine.edu

Collinearity – the reality of digital photogrammetry

- Collinearity – the ground point, the nodal point of the lens, and the image point all lie in a straight line
- The ground point is defined by 3 unknowns – X, Y, Z
- The image point is defined by 2 measurements – x,y photocoordinates
- The nodal point of the lens is called the exposure station. It has six unknowns – 3 coordinates – X,Y,Z (in the same system as the ground point) and 3 rotations defining the direction of the camera axis relative to the ground coordinate system. The rotations are historically Greek letters omega phi kappa about X, Y, and Z respectively.
- We will let W, P, K represent omega, phi, kappa respectively. Note kappa (about Z) relates mostly to the direction of flight relative to the ground coordinate system.

Collinearity

- For a point a on a photo derived from exposure L
- x_a,y_a = a's photocoordinates
- X_A,Y_A,Z_A = A's ground coordinates
- W_L, P_L, K_L, X_L, Y_L, Z_L = exposure L's unknown camera angles and coordinates

The Collinearity condition

- $x_a = f(W_L, P_L, K_L, X_L, Y_L, Z_L, X_A, Y_A, Z_A)$
- $y_a = g(W_L, P_L, K_L, X_L, Y_L, Z_L, X_A, Y_A, Z_A)$
- Where f and g represent mathematical functions
- The measured photo coordinates are a function of the exposure station unknowns and the ground station unknowns.
- This is an observation equation – the measurement is described in terms of the unknowns.

Ground control and collinearity

- Ground control is either
- (1) targeted (a plastic, fabric, or painted cross or “T”) in an open location such as a road intersection or parking lot. This requires marking the control point before the flight.
- (2) Photo id’s or “Picture points” – monoscopically identifiable points are located after the flight has occurred – manholes, sidewalk intersections, end of paint stripes, etc.

Exposures and collinearity

- Historically the exposure station unknowns had to be solved based on measured ground control coordinates.
- Today airborne GPS and IMU (Inertial Measuring Unit, i.e. gyroscopes) are used to measure the exposure station position and orientation. GPS-IMU has accuracy limitations and thus cannot be relied on for precise engineering product.

Collinearity applications

- Bundle adjustment – simultaneous solve for all ground coordinates of all points with measured photocoordinates along with all exposure unknowns

Historical Aerotriangulation (AT)

- Control densification by photogrammetry to minimize ground control requirements and validate harmony of ground control and photocoordinate measurements
- Today measured exposure station unknowns by GPS-IMU are included
- Requiring multiple control points in every stereomodel would be cost and time ineffective if AT can provide “bridged” control between a sparser ground control network

Historical Aerotriangulation (AT)

- Consisted of 3 primary mathematical steps after all photocoordinates were measured
- (1) relative orientation – create unique assumed 3-D model coordinates for each stereomodel
- (2) (a) strip/block adjustment – combine all unique model coordinates systems into one combined unique coor. system using common points between stereomodels and flight lines
- Strip combines models along a flight line
- Block combines flight lines after joined by Strip
- (2) (b) strip/block adjustment – convert the common assumed system into the ground coor. system using measured ground control points

Historical Aerotriangulation (AT) step 3

- Bundle adjustment – the simultaneous least squares best fit of all photo coordinates, measured ground control coordinates , and measured exposure station coordinates solving for any remaining unknown parameters
- The bundle adjustment was too mathematically intense till main frame computers existed, and is of course routine on today's personal computers
- Relative orientation and the strip/block adjustment provide the initial approximations for all unknown parameters in the bundle adjustment

Historical Aerotriangulation (AT)

- Three unknown points are selected near the middle of a photo, one each near the top, middle, and bottom of the photo – called pass points as they pass control
- These three points could be distinct images, or could be artificially marked by a small drill into the photo called a "pug" as the instrument is called a pug machine
- Due to 60% overlap, these three points will appear in the photo immediately left or right along the flight line (end photo only overlaps in one direction)
- If multiple flight lines the top and bottom points usually appear in the overlap between flight lines (20% overlap is common across flight lines) – these pass points are also tie points as they "tie" across flight lines

Historical Aerotriangulation (AT)

- A point in the overlap region across flight lines could potentially be on 6 photos, 3 photos on each line, due to 60% endlap along the flight lines and 20% sidelap across flight lines
- Along a flight line points in the middle of a photo can be viewed in 2 stereomodels as it is a right photo in one stereomodel and a left photo in the second stereomodel
- It is imperative these points in the middle of the photo are not too far left or right to not be in two consecutive stereomodels

Historical Aerotriangulation (AT)

- A pug (artificial) mark takes advantage of superimposition
- When viewed in stereo, the pug mark “appears” to be in the photo in which it is not marked, and thus in stereo can be measured on the un-marked photo
- If the point is monoscopically identifiable measurement does not require stereo viewing
- In addition to pass points, ground control points are also measured when viewable

Historical Aerotriangulation (AT)

- Thus a stereomodel has six pass points in it, plus possibly some control points.
- The left three points overlap into the next stereomodel to the left.
- The right three points overlap into the next stereomodel to the right.
- A unique point is assigned the same point name/identifier no matter what photo it is measured on. Usually the point name is derived from what photo’s center the point is on. Control points usually use the point name assigned by the surveyor who put ground coordinates on it.

Bundle adjustment

The relative orientation and strip/block adjustment help find blunders and set up the bundle adjustment with initial approximations

Possible input to bundle adjustment

Photo coordinates – collinearity

Ground Control coordinates

Exposure station coor. and angles (if airborne GPS-IMU is used)

Bundle adjustment

- Output of bundle adjustment
- Ground X,Y,Z of any points with measured photo coordinates
- W,P,K,X,Y,Z of all exposure stations
- It is a simultaneous least squares solution so does not contain the problem of systematic error buildup as in rel. or., strip, block adjustment process

Bundle adjustment

- Least squares is enhanced by proper user defined error estimation
- Photo coordinates error est. of 3 -20 microns depending on quality of imagery and abilities of photogrammetrist
- Ground control error estimates are desired to be fixed (0.001 ft. is mathematically the same as fixed) but in reality no survey product is perfect, and no photogrammetrist can measure exactly the same point the surveyor measured as images have to be visually “interpreted:
- Exposure station coordinates and angles are derived from the GPS-IMU processing that is measurement based and thus is not perfect

Bundle adjustment

- Ground control error estimation
- Larger error estimates could be place on picture points than targeted control as a target is better defined both in a ground survey and in measuring an image on a photograph
- Larger error estimates would be placed on traverse derived coordinates vs. fixed ambiguity GPS coordinates
- Larger error estimates would be placed on trig. Leveling derived elevations vs. those derived from differential leveling

Bundle adjustment

Least squares minimizes the sum of the squares of (weight * residual)

Where weight = 1 / error estimate

Note residual / error estimate is unitless.

This allows the proper mixing of different types of measurements (photo coordinates, ground control coor., exposure measurements) properly in one simultaneous analysis

Bundle adjustment control requirements - Historical

- Pre airborne GPS-IMU
- Mathematically 2 X,Y,Z control points and 1 Z only control point define a 3-D coordinate system and will allow the bundle adjustment to function
- Unfortunately no check in the quality of the control coordinates would exist
- Errors would propagate significantly on a large job where the control is separated by significant amounts of photos

Bundle adjustment control requirements - Historical

- Pre airborne GPS/IMU
- Mathematically bundle adjustment is weaker in vertical than horizontal because the triangles created by collinearity are longer and skinnier in the vertical dimension
- Thus rule of thumb realistic to prevent significant error propagation – horizontal control every 4-6 photos, vertical control every 3-4 photos. More vertical control attempts to tighten up the weaker vertical geometry of AT/collinearity
- Realistically using GPS all control is 3-D so concept of a 2-D or a 1-D only control point goes away.

Bundle adjustment control requirements – using airborne GPS-IMU

- Mathematically no ground control is required as the exposure unknowns have been determined
- Realistically control should be placed in the 4 corners of the job to provide a realistic check on the GPS-IMU solutions
- Note GPS-IMU is not yet accurate enough to serve as control for precise engineering design photogrammetric projects

Bundle adjustment control requirements – using airborne GPS-IMU

- Note one of the reasons for relative orientation and strip adjustment was to generate approximations for exposure station unknowns
- If GPS-IMU is used, the exposure unknowns become measured. They can be used to solve for any ground coordinate approximations using collinearity, and thus the need for relative or. and strip adjustment prior to the bundle adjustment is eliminated.

Bundle adjustment

- Residual rule of thumb (all adjustments)
- If a residual is more than three times its corresponding error estimate you are 95% confident something is suspect
- Residuals will be larger than its corresponding error estimate approximately 33% of the time – in other words at one standard deviation residuals will be less than their error estimates 67% of the time
- So do not worry if a residual is larger than an error estimate – start worry when it starts to get near three times the size of the error estimate

Bundle adjustment

- But be careful – Example
- Unusually large photo coordinate residuals exist on a ground control point
- Re-measuring the photo coordinates on that point produced no different results
- If the control point's ground coordinates were held fixed, it is very possible that is the source of the problem. By fixing the control it cannot adjust – residuals are zero- so the misfit is converted into the photo coordinates as those were assigned reasonable error estimates.

What happens in map collection

- A point on the right photo can only be measured along an epipolar line given a left photo x,y (the original parallax concept)
- Comparator coordinates convert to photo coordinates. Left and right photo coordinates convert to model coordinates. Model coordinates convert to ground coordinates via the resolved orientations.

Vector (Map) compilation

- Vector (points, lines, and text) is one form of map product derived from photogrammetry
- A user digitizes vector information in stereo viewing at recognizing the feature code/attribute of an image
- Points (manholes, trees, light poles, power poles, hydrants, etc.) are point feature codes represented by a user defined symbology at a user defined scale.
- In computer aided drafting points normally are stored in a layer/level associated with the feature code name, and the symbol is a defined block/cell.

Vector (Map) compilation

- Lines (centerlines, pavement edges, curbs, sidewalks, power lines, etc.) are line feature codes that are associated with symbology of color, line width, line style, straight/curve, etc.)
- Lines are segregated in computer-aided drafting by a feature code being assigned with a layer/level.

Vector (Map) compilation
Tricks in software to enhance mapping

- (1) close a line – obvious use is buildings – after digitizing last point automatically close the building (back to the first point)
- (2) make angles 90 degrees – for certain features (buildings are a great example) if a corner is within a user defined angle of 90 degrees make it a 90 degree angle
- (3) parallel line offset – great on roadways for centerline, pavement edge, curbs, sidewalks, ditches, etc, that are parallel – should include option for a vertical offset (such as on curbs)
- This can include how certain features (sidewalks) intersect other features (driveways)

Vector (Map) compilation
Tricks in software to enhance mapping

- (4) Extend undershoots and trim overshoots – This is also usually associated with how certain feature codes interact with other feature codes
- Example – a driveway should intersect the edge of a building but when digitizing the driveway will be short or past it. Automated software can fix these while collecting the data

Vector (Map) compilation Tricks in software to enhance mapping

- (5) Connect end points near each other - snap (near defined by user defined distance input)
- Example – Two sidewalk edges were digitized but connect at a common point collected on two different lines – If these two endpoints are within the user defined tolerance it should be snapped together
- Many line joins occur when features continue across distinct stereomodels or flight lines

The other superimposition

- The display of vector information superimposed on the raster stereomodel is the perfect way to see if all information has been digitized
- Superimposition is also used in map updating – a new flight is viewed with an old digital map superimposed on it. Changes due to construction, etc. can be seen and updates made to the existing digital map information
- Prior to computerization the display of vector information overlaid on raster information was very impractical.

The traditional work flow

- (1) large format calibrated aerial cameras with a specific mount in an airplane
- Today this could be a digital camera.
- Today a film based or digital camera could have GPS-IMU also in the ariplane to solve for exposure station position and orientation

The traditional work flow

- (2) processing of photogrammetry in one-to-one production of images on film or glass diapositives specifically designed for minimization of distortion during production and due to temperature, pressure, and humidity changes
- Today film imagery uses a high precision scanner to convert to a digital format
- Image from a digital camera are already in a computer format (usually Mr. Sid, JPEG, TIFF, etc.)

The traditional work flow

- (3) a realistic amount of ground control which is either targeted or photo identifiable
- Control accuracy requirements are a function of flying height and desired product accuracy
- Ground control requirements can be minimized in higher altitude lower accuracy jobs by airborne GPS-IMU

The traditional work flow

- (4) a measurement and ensuing least squares analysis process called aerotriangulation which validates the ground control and densifies it to a suitable point for use in stereoplotter orientation and map compilation,
- Small jobs may be “full fielded” with control and aerotriangulation can be by-passed
- GPS-IMU may eliminate the need for aerotriangulation in lower accuracy jobs

The traditional work flow

- (5) stereoplotter orientation based on the densified ground control which resolves the relation of the photos to each other and the ground at the time of exposures and provides a check on the quality of the aerotriangulation
- This is completely automated if aerotriangulation and/or GPS-IMU exists.
- This can be used to estimate horizontal and vertical misclosures between adjacent stereomodels and across flight lines.

The traditional work flow

- (6) compilation of the desired features which could include planimetric features (line and point symbology), contours, cross sections, profiles, break lines, spot elevations, and text information
- It is simply a feature code based collection approach similar to topographic survey collection
- Many map clean-up functions (connecting edges of pavement across stereomodels, driveways intersecting buildings, etc.) are automated during the collection process

The traditional work flow

- (7) clean-up of compiled information to make it topologically pleasing (an edge of driveway should not extend past the outline of a house),
- The automatic process obviously will not resolve all map editing
- Text, feature code tables, etc. can also be added during this process

The traditional work flow

- (8) addition of field survey data where the data could not be collected photogrammetrically due to obstructions, cover, shadow, etc.,
- A photogrammetrist can only map what one can see.
- If underground utilities are required they are added in this process.

The traditional work flow

- (9) production of final products which could include translation to other digital map formats and/or hard copy output.
- Typical output formats are AutoCad drawing (.dwg, .dxf), Microstation drawing (.dgn), and ESRI shape files (.shp)
- Today digital image products such as orthophotos are another standard product (will be discussed in soft copy photogrammetry)

The traditional work flow

- In translation to final output format softwares usually allow user definition of product feature code, color, symbology, layer/level, line style, line type, etc.
- Example – During collection buildings may be collected with feature code BLDG, color red, standard line type and be converted to feature code BDG, layer BUILDING, color green, and dashed lines.

Evolution of stereoplotters

- Digital stereoplotters
- No film, only scanned image viewing on computer scree
- Infinite zoom (to pixel level)
- Computer screen superimposition
- Computer and viewing glasses are only hardware so no dedicated unique hardware
- Image enhancement tools
- Computer software can attempt to make some measurements via pixel matching/image identification
- No need to ever re-orient a stereomodel as all parameters are digitally stored for a scanned image

Historical Elevation Collection in Photogrammetry

- Before modern computerization elevation product was in the form of contours, profiles, and cross sections. In some cases volume determination was made by a grid of collected elevations, but this is really no different than a series of cross sections.
- Profiles and cross sections were simply measurements of elevation (viewing in stereo and measuring with the floating mark). If a desired point could not be collected due to trees or shadows you either skipped that point or collected a point as close to it as possible and assumed it was at the same elevation.
- One would assume contours would be interpolated from spot elevation collect but instead ….

Historical Elevation Collection in Photogrammetry

- Stereoplotter operators attempted to “trace” a contour by visualizing the floating mark touching the ground at a series of same elevations.
- This procedure works great along a bank, and does not work well in a flat area. But in a flat area it does not matter where the contour is shown as it is within a reasonable tolerance anywhere on that flat surface.
- Drafters would trace over the stereoplotter drawn contour as it was usually jagged (due to trying to follow a line of elevation visually) to smooth it out to cartographic standards

Modern Elevation Collection in Photogrammetry

- Manual elevation collection in photogrammetry today involves collection of points and break lines to build a 3-D model from which any contours, profiles, cross sections, volumes, etc. can be extracted
- Certain feature codes in mapping lend them to being elevation points (ground shot, manhole, drain, etc.) and break lines (curbs, pavement edges, sidewalk edges, ditches, etc.)
- Certain feature codes in mapping are generally not elevation points (power poles, light poles, etc.) and not break lines (fences, buildings, power lines, etc.)
- Thus elevation collection can be mostly defined by the feature coding process of topographic mapping

Airborne GPS-IMU

- Obviously static GPS will not satisfy the needs or positioning a camera in an aircraft.
- Kinematic GPS means each epoch is it own unique solution; kinematic GPS utilizes a base and rover to produce vectors from the base to the rover.
- If the base has known coordinates, the GPS vector to the rover enables calculation of each rover position

Airborne GPS-IMU

- Historically (early 1990’s) the rover unit had to be set up on a known point before the flight mission started
- Mid 1990’s saw the development of OTF – On-The-Fly ambiguity resolution – the vector could be resolved to survey accuracy without rover occupation of a known point, and in theory the ambiguities can be resolved without the rover ever in a static position

Airborne GPS-IMU

- Could RTK be used instead of post-processed kinematic
- Radio based RTK (claims of 6 miles) would never support the base to rover distances
- Cell coverage for RTK corrections might work but remember on commercial airlines your phone has to be off while in flight
- Data collection for RTK is really not set up for fast collection rates of massive amounts of points as that is not how you do a ground survey

Airborne GPS-IMU

- Goal in all precise GPS is to reach a fixed ambiguity solution – which means the number of wavelengths from satellites to both base and rover have been exactly resolved.
- If a plane does not bank hard, and assuming there are no obstructions on a runway, a rover should never lose satellite lock and therefore maintain a fixed ambiguity solution
- In reality, the airplane usually stays static prior to flight, and can return to static after a flight, making ambiguity resolution easier.

Airborne GPS-IMU

- The airborne GPS receiver and the camera are time synchronized – thus GPS knows when an exposure is occuring
- The GPS receiver is not at the exposure station. Thus when an airplane is mounted with a GPS receiver and camera for the first time the 3-D offset from phase center of GPS antenna to nodal point of the lens must be surveyed.

Airborne GPS-IMU

- The exposure does not go off at an exact GPS epoch. Thus the historical approach was to interpolate between epochs to determine where the antenna was at the exact time of exposure.
- Today IMU can be used to measure thousands of coordinate differences between GPS epochs, and it can then be used to better calculate the antenna position at the time of exposure
- IMU, i.e. very precise gyroscopes is also used to very precisely measure camera angles at the time of exposures

Airborne GPS-IMU

- Today CORS stations are routinely successfully used as base stations in airborne GPS processing. This eliminates the need to set a base near the job site in an open area.
- The major improvements in kinematic GPS processing in the last few years have been the ability to process longer base to rover baselines, enabling use of CORS as base stations

Airborne GPS-IMU

- Single frequency receivers have been successfully used on the aircraft as long as satellite lock is not lost. Single frequency takes longer to gain or re-gain ambiguity solution. But waiting for clearance on a runway is usually long enough (10 minutes) for a single frequency receiver to resolve ambiguity

Airborne GPS-IMU

- The future in airborne GPS processing will be Precise Point Positioning (PPP). No base stations, thus no vectors are calculated. Instead a precise satellite ephemeris is used along with new point positioning mathematics, to resolve ambiguities. This algorithm is free and currently available from the Canadian equivalent of the National Geodetic Survey.

Airborne GPS-IMU calibration

- Called a bore site – it is simply a dense series of precisely coordinated targets in a local area
- A traditional aerotriangulation solves for the exposure unknowns, which can be compared to what is derived from airborne GPS-IMU
- IMU can become systematically off over long periods of time. The bore site resolves the systematic error in the calibration process.

Soft copy (digital) photogrammetry measurement enhancements

- Infinite zoom does make it possible to make more precise manual measurements in some cases but:
- A digital photo is a series of pixels that have gray tone or color characteristics that permit some automated measurement
- (1) Find a known image pattern – The classic example is a fiducial mark. It has a consistent appearance in a very defined region of the photo. Thus pattern recognition enables automated measurement of fiducial marks, hence inner orientation can be automated.

Soft copy (digital) photogrammetry measurement enhancements

- (2) Image matching in overlapping photos
- Through gray tone or color matching of a series of pixels on two overlapping photographs, it is possible for computer software to “match” pixels in the same way an operator matches pixels in stereo by placing the floating mark on the ground.
- If a point is in multiple stereomodels or flight lines, this matching process can continue.
- Example – Software could identify by image matching the same ground point as six individual pixels on six photos (overlapping stereomodels and flight line)

Soft copy (digital) photogrammetry measurement enhancements

- At first it appears matching common imagery in two overlapping photos requires comparison of many pixels
- But using the properties of a steromodel
- (1) Once relative orientation is complete, or GPS-IMU is used for measurement of orientation, the corresponding epipolar line defines a line of pixels, parallel to the flight line, that a image match must exist on. Thus this eliminates all but a line of pixels for a match.
- Resampling is a process where the pixels are reoriented so a viewer in stereo changes parallax along an epipolar line parallel with his viewing. This keeps the pixels from having to shift up or down to adjust to the epipolar line not being exactly parallel with the photocoordinate x axis.

Soft copy (digital) photogrammetry measurement enhancements

- Continuing with properties of a stereomodel
- (2) The matching pixel can only be a fraction of the pixels along that epipolar line because one knows the approximate overlap, and that the parallax change is limited in magnitude by changes in elevation are limited relative to the flying height.
- Example – For a 1200 ft. flying height one would not expect elevation change of 600 ft. in a stereomodel. Unless very large buildings or very mountainous terrain exists, that possible elevation change across a stereomodel is probably less than 100 ft.

Soft copy (digital) photogrammetry measurement enhancements

- Thus limited parallax change limits how many pixels need to be searched along an epipolar line for an image match.
- (3) Once a match is made, that pixel cannot be used for matching to that overlapping photo anymore. Thus the more successful matches that have been made limit the search range that needs to exist, and the number of pixels that need to be considered as matches can be removed from the search.

Soft copy (digital) photogrammetry measurement enhancements

- When does image matching fail
- (1) When shadows or changing sun angle change the gray tone or color of the same point on overlapping photos.
- (2) When all pixels in a given area have the same gray tone or color. A newly paved road parallel to the flight line will have lots of pixels that look alike to a computer program

Soft copy (digital) photogrammetry measurement enhancements

- So where is automated image matching used?
- (1) Aerotriangulation – Pass points can now be totally computer measured. The algorithm can be extremely picky at matching because traditional AT only used 6 points per stereomodel. Since image matching usually is quite successful with even picky analysis, literally hundreds of AT pass points can now exist in overlapping photos because measurement is automated
- Note ground control points still are manually measured as they require human identification.
- Since the automated measurement process creates so many pass points beyond what is needed, it is possible to automatically run the bundle adjustment multiple times thinning out the highest photocoordinate residuals.

Soft copy (digital) photogrammetry measurement enhancements

- So where is automated image matching used?
- (2) “Auto” DTM collection- a little less picky in image matching than in AT – every image match generates a X,Y,Z based on collinearity and/or absolute orientation
- Instead of a operator manually collected DTM in stereo, the computer is attempting this process automatically

Soft copy (digital) photogrammetry measurement enhancements

- Limits to “Auto” DTM
- No break lines are collected
- Like LIDAR, points not on the ground are collected as the computer program cannot discriminate between buildings, trees, and ground.
- Engineering design DTM’s are thus usually collected manually as they only include the ground points and break lines. “Auto” DTM is better for elevation correction in orthophotography which will be discussed next.

Soft copy (digital) photogrammetry measurement enhancements

- How accurate can a digital image be measured.
- Current automated image measuring /processing can measure to ¼ of a pixel
- A pixel is the smallest image unit of the scanned image, or the smallest image unit resulting from a digital camera
- Example – a 30 micron pixel size will usually result in 30/4 = 7.5 micron automated measuring ability

Image based products pre-digital photogrammetry

- (1) Rectified photo – a diapositive was projected onto a plot of control points; the diapositive is moved inwards and outwards and tilted relative to the plot of control points till a visual best fit is achieved. This is an eyeball approach to scale and tip, tilt, azimuth correction. The projected image (corrected) is then photographed.

Image based products pre-digital photogrammetry

- (2) orthophotography – Note looking down at all points instead of a perspective view
- A stereoplotter is fitted with a camera that only takes a small narrow picture straight down of the image
- An operator manually corrects for elevation differences using the floating mark
- A narrow picture is taken straight down, and the series of narrow pictures is seamed together during the photography process (multiple exposures) to create an orthophoto

Image based products pre-digital photogrammetry

- (3) Mosaics – the seaming together of multiple raw photos, rectified photos, and/or orthophotos
- Prints that overlap are sliced with a razor blade along a desired common image line, and are then pasted together
- Touch up paint along the pasted seams is used to cover up the paste, and to make images from multiple photos match up better with gray tone
- Thus an entire job, consisting of many photos, can be turned into one mosaic

Image based digital products

- Delivering an image (raster) product instead of a vector product
- (1) raw scanned photo or photo directly from aerial digital camera – similar to a photo from a hand held camera except usually a lot more pixels/storage – this has use if being used for pictorial purposes only

Image based digital products

- (2) Scaled, rotated, and translated image to fit ground control – a 2-D conformal or 2-D projective (8 unknowns which relate

2-D systems that are not parallel to each other)

This approach ignores elevation information and thus any elevation differences in the image will relate to error due to relief displacement being unaccounted for

Image based digital products

- (3) Rectified photo
- One average elevation is used in projecting the image to a defined projection such as state plane or UTM
- Differences from the defined average elevation will create error in image due to relief displacement

Image based digital products

- (4) orthophotography
- An elevation model (DEM, DTM, etc.) derives independent elevations for each pixel in projecting them to the defined map projection
- The quality, or lack of quality, of the elevation model defines the quality of the correcting the pixel to its datum position

Image based digital products

- How are elevations used to correct pixels to their projection location
- Recall collinearity
- $x_a = f\ (W_L, P_L, K_L, X_L, Y_L, Z_L, X_A, Y_A, Z_A)$
- $y_a = g\ (W_L, P_L, K_L, X_L, Y_L, Z_L, X_A, Y_A, Z_A)$
- The exposure unknowns are derived from airborne GPS-IMU or aerotriangulation
- Ground X_A, Y_A, Z_A is what the DEM/DTM is composed of

Correcting for elevation

- The right hand side of collinearity is thus defined, and the corresponding photocoordinates given a ground X,Y,Z can be calculated.
- If a ground X,Y,Z calculates photo x,y that is not on the photo image format – that point is not on this particular photo.

Correcting for elevation

- Where is that point's correct projection position in terms of photo x,y?
- A projection is at a defined elevation or ellipsoid height. The latter is more correct but not as well understood by the general population.
- Most projections are defined at an elevation of zero! Thus a ground Z of zero is substituted for the actual point's ground Z and the photocoordinates are recalculated by collinearity.

Correcting for elevation

- The point's correct orthographic projection location has thus been determined based on the ground Z of zero.
- The image point has moved from a photocoordinate based on DEM/DTM elevation (perspective location) to where it would be if it could be viewed at an elevation of zero (on the projection – an orthographic location)

Correcting for elevation

- Vertical objects are a small problem in orthophotography
- Example – A power pole or building edge occupies 5 pixels on a raw photo. All 5 pixels need to be projected to the same location are all are at the same projection X,Y (vertical pole/building edge assumed)
- 5 pixels projecting to one pixel leaves no image for 4 pixels in the resulting orthophoto. This is because the image on the backside of the vertical object could not be viewed as it was blocked by the perspective nature of the vertical object

Correcting for elevation

- For better or worse, a standard DEM to use for orthophoto production are the free USGS DEM's available for download on the Internet
- Most of these were converted by interpolating from contours on the original USGS quadrangle maps which were mostly compiled in the 1940's-1950's from flying heights of 25000 ft. using Kelsh stereoplotters including areas where lots of tree coverage exists.
- USGS DEM's thus can have significant error in them that can only be validated through ground truthing
- Note error in ground X,Y also causes errors in orthophoto accuracy as the DEM will be associated an incorrect X,Y will a raw pixel.

Correcting for elevation

- The best DEM for orthophoto production is the "Auto" DTM produced from automated image matching of the actual photography that is being converted to orthographic.
- But even that will have error in image matching due to errors discussed previously (shadows, no change in gray tone, etc.)
- Note an engineering design DTM is ground only, and an image contains building, trees, etc. that need proper elevation correction. "Auto" DTM has this information while a ground engineering design DTM does not.

Mosaic

- Since each rectified or orthophoto now has a ground X,Y,Z associated with each photo x,y – by coordinate comparison it is simply to merge individual photos into one composite mosaic.
- Software attempts to use as much of the centers of photos as possible as this minimizes relief displacement.
- One mosaic thus can often be called one orthophoto for the entire job. In very large jobs multiple mosaics are created and called orthophotos simply because one file could become unmanageable due to file size.

Why are aerial digital cameras so great?

- Scanners for photogrammetric accuracy can cost from $50,000-$200,000.
- Time is involved in collecting film based photography, processing the film, then scanning the diapositives.
- Aerial digital cameras produce digital images and remove all film processing and scanning.
- No film distortions, including shrinkage and expansion, exist in image from a digital camera

Automation via Digital photogrammetry

- (1) A digital camera collects the data, and GPS-IMU is used in conjunction with the digital camera
- (2) The digital files are downloaded. GPS and IMU can be processed relative to raw data at existing CORS stations so no ground based GPS needs to exist.
- (3) Automated image matching occurs for both AT and Auto DTM
- (4) AT can occur if the GPS-IMU results is deemed not accurate enough.
- (5) Auto DTM enables DTM's to automatically be built for the coverage area. Automated orthophoto production can occur, and the produced orthophotos can be automatically seamed together to produce one overall orthophoto mosaic which is copied to a DVD and delivered to the client.

Mosaic

- The best seam for merging photos is in grassy, water, or similarly paved areas where the same gray tone exists.
- Software can easily change gray tone or color hues along a seam line to make images from multiple photos match up better – it is almost impossible to find seams in modern digital mosaics!

The future

- A digital aerial camera solves all film based problems.
- A fast computer in the airplane will process the GPS-IMU near real time.
- The GPS-IMU will satisfy accuracy requirements without aerotriangulation.
- The fast computer in the airplane will perform auto-DTM.
- The fast computer in the airplane will create orthophotos and mosaic them creating seamless data.
- The complete orthophoto will be copied to a DVD and be deliverable when the plane lands.
- Vendors are saying the future is close to now!

Example aerial digital cameras

- Note design of digital aerial cameras creates a different dimension in x (flight line) vs. y in format.
- Most metric aerial digital cameras until recently had shorter focal lengths than the standard 6 in. of film based metric camera

Example aerial digital cameras

- RolleiMetric AIC
- Resolution 16-39 MegaPixel
- Image size 36x36mm or 38x48mm
- focal lengths 40, 50, 80, 120, or 150 mm
- shutter speed up to 1/1000 sec.
- from calibration 5440 pixels in x, 4080 pixels in y,

Example aerial digital cameras

- Intergraph/ Zeiss DMC II 6846x6096 pixels 42 Megapixel, 7.2 um pixel,
- Focal length 45 mm
- Pan camera is 17216x14656 250 Megapixel, 5.6 micron, focal length 112 mm

Example aerial digital cameras

- Intergraph/ Zeiss RMK D
- 45 mm focal length 7.2 um pixel sensor size 5760x6400 pixels (41.47x46.08 mm)
- 42 MegaPixel

Example aerial digital cameras

- NexVue (specksystems)
- 4906x3678,18 mpixel, 9 um, 50 mm. foc
- 6496x4872,31.6 mpixel, 6.8 um, 50 mm foc
- 7216x5412, 39 mpixel, 6.8 um,
- 50 mm focal length

Example aerial digital cameras

- Ultracampxp by Vexcel
- 11310 pixels in x, 17310 pixels in y, 195 Megapixel, 6 um CCD sensor, 100 mm focal length,
- advertises 1 um rms AT residuals
- UltracamL is 9735x6588 pixels
- Panchromatic and multi-spectral separate (9 pan and 4 color arrays)

Example aerial digital cameras

- Leica ADS40 2nd generation
- 12000 pixel wide swath
- Simultaneous panchromatic, color, color-infrared, all multi-spectral bands

Example aerial digital cameras

- Z/I Imaging DMC (Digital Mapping Camera)
- Frame sensors rigidly mounted
- 4 high resolution panchromatic camera heads and 4 multi-spectral heads
- Can handle diverse light and has Forward Motion Image compensation (FMC)

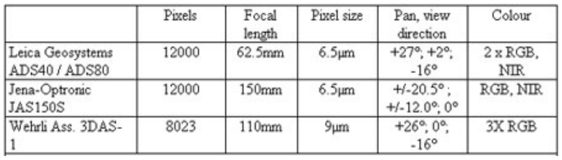
Example Digital Metric Cameras

- DiMAC – large format frame 10,500 pixel wide swath.
- 4 images simultaneously possible of true color and infrared
- Has FMC

Example aerial digital cameras

- Line scan cameras have to be used in combination with direct sensor orientation (combination of GPS with inertial system) to enable a correct geo-reference. They are imaging permanently the flown area. The sampling rate determines the possible object pixel size in flight direction. The ADS40 and the JAS150S have a maximal sampling rate of 800 lines/sec, the ADS80 is in the range of 1000 lines/sec while the 3DAS-1 has 250 up to 750 lines/sec. This limits the smallest object pixel size in flight direction to approximately 8cm for the low flight speed of 250km/h (Table 2).

Example aerial digital cameras
Table 2



	Pixels	Focal length	Pixel size	Pan, view direction	Colour
Leica Geosystems ADS40 / ADS80	12000	62.5mm	6.5µm	+27°; +2°; -16°	2 x RGB, NIR
Jena-Optronic JAS150S	12000	150mm	6.5µm	+/-20.5° ; +/-12.0°; 0°	RGB, NIR
Wehrli Ass. 3DAS-1	8023	110mm	9µm	+26°; 0°; -16°	3X RGB