# CAMERAS AND OTHER IMAGING DEVICES

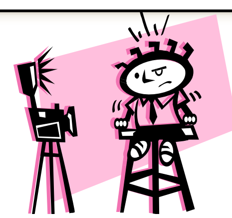
Center for Photogrammetric Training

Ferris State University

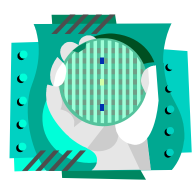
The Center for Photogrammetric Training


RCB

## CAMERA

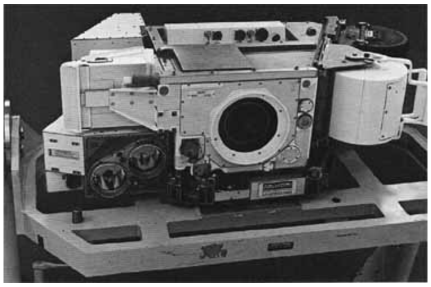


- Light-proof chamber or box in which the image of an exterior object is projected upon a sensitized plate or film, through an opening usually equipped with a lens or lenses, shutter and variable aperture
- In digital photography – use semiconductor electronics instead of film



## CATEGORIZING IMAGING DEVICES

- Frame camera (sensor)
  - Acquire image simultaneously over entire format



- Strip cameras, linear array sensors, pushbroom scanners
  - Sense only a linear projection or strip
- Flying spot scanners, mechanical scanners
  - Build image by detecting small spots at a time

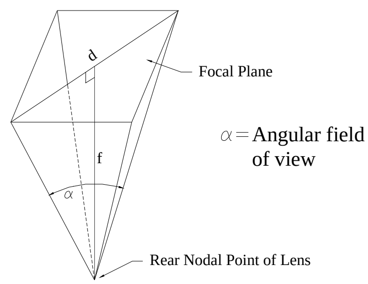
## AERIAL MAPPING CAMERA REQUIREMENTS

- Lens of high geometric quality
- Capable of exposing large no. of photos in rapid succession to exacting specifications
- Short cycle time
- Fast lenses
- Efficient shutter
- Functional under extreme weather conditions, like temperature and humidity, in spite of aircraft vibration
- Simple to use during photo mission
- Equipped with safeguards to protect against operator blunders
- Automatic as possible
- Able to preserve elements of interior orientation and preserve internal geometric relationships

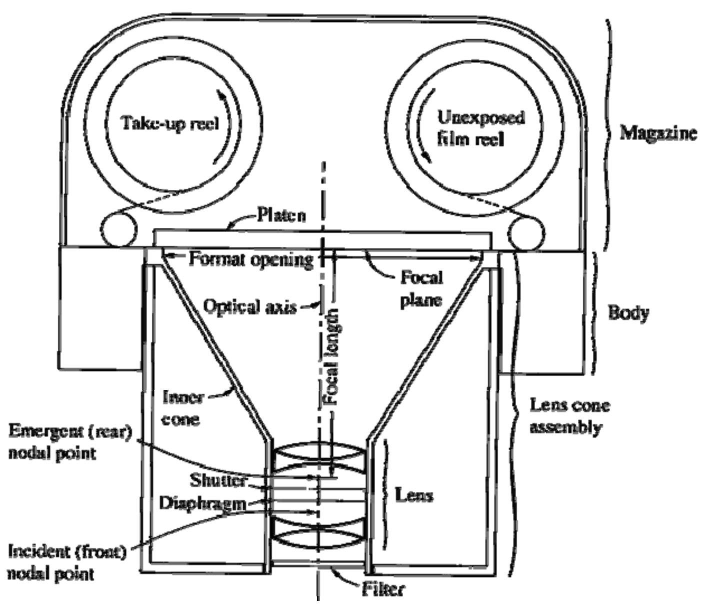
# SINGLE LENS FRAME CAMERA

- Lens held fixed relative to focal plane
- Film generally held fixed
- Classified by angular field of view
  1. Normal angle (up to 75°)
  2. Wide angle (75° – 100°)
  3. Superwide angle (> 100°)
- Angular field of view

$$\alpha = 2\tan^{-1}\left(\frac{d}{2f}\right)$$




# AERIAL CAMERA PARTS



## LENS

- Gathers light rays from object space and brings them into focus in the focal plane behind the lens
- Array of lenses aligned in lens cone

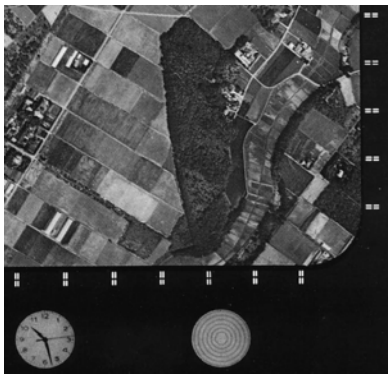
## FOCAL PLANE

- Plane where all incident light rays brought to focus
  - Aerial cameras have focus fixed for infinite object distance – set focal plane equal to focal length behind rear nodal point
- Defined by upper surface of focal-plane frame
  - Surface where film emulsion rests

Fiducial marks
- Index marks imaged on film
- Serve as reference photo coordinate system

## FIDUCIAL AND RESEAU

- Example of Zeiss Jena



- Example fiducial


## FORWARD MOTION COMPENSATION

- Move film slightly across focal plane during exposure in flight direction
- Example (3.1) Camera with f = 152.4 mm, airplane velocity = 200 km/hr, flying height above terrain = 3,500m, exposure time = 1/500 sec. What distance (in mm) must film move across focal plane to obtain clear image?

# FORWARD MOTION COMPENSATION

- Solution:
  - Distance plane travels during exposure

$$D = (200\ \text{km}/\text{h})\left(\frac{1}{500}\text{sec}\right)\left(\frac{1\ \text{hr}}{3600\ \text{sec}}\right)\left(\frac{1000\ \text{m}}{1\ \text{km}}\right) = 0.11\ \text{m}$$

  - Distance image moves during exposure

$$d = 0.11\ \text{m}\left(\frac{152.4\ \text{mm}}{3500\ \text{m}}\right) = 0.005\ \text{mm}$$

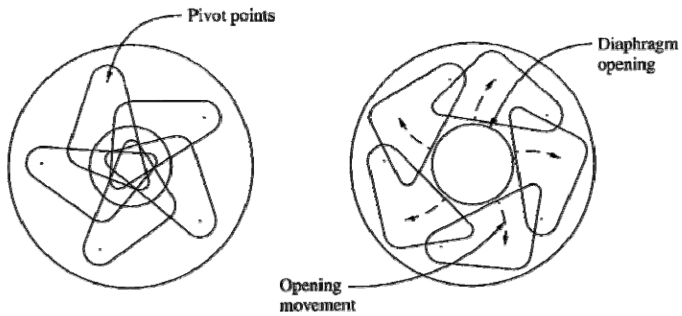
# SHUTTERS

- Important that shutter be open for very short duration
  - Reduces detrimental effects of aircraft vibration
- Types of shutters
  - Between-the-lens shutter
    - Mapping cameras
  - Focal plane shutters
  - Louver shutters

- Blade-type shutter
  - Between-the-lens shutter
  - Consists of 4 blades
    - 2 for opening
    - 2 for closing
  - Similar to guillotine

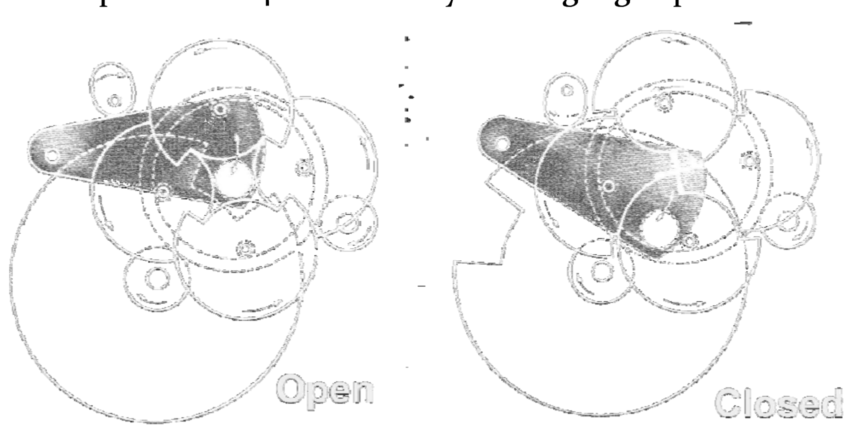
## LEAF-TYPE SHUTTER

- 5 or more leaves mounted in pivots
- When shutter opens, leaves rotate about pivot to open position
- Some cameras use 2 sets of leaves, one for opening, one for closing




## ROTATING DISK SHUTTER

- Consist of disks rotating – high reliability and efficiency
- Example  Zeiss – 4 continuously rotating high-speed disks

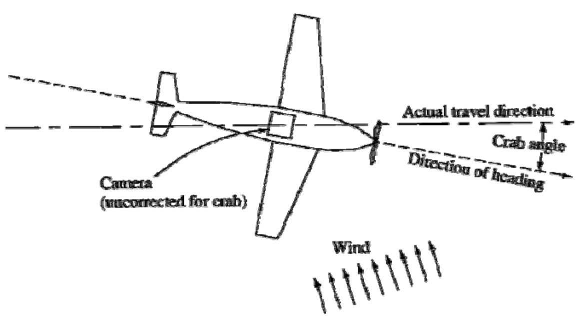


# SHUTTERS

- Focal plane shutter
  - Located front of focal plane
  - Curtain type most common
  - Curtain contains a slit
  - Exposes different areas of focal plane at different times
- Louver shutter
  - Consists of a number of louvers
  - Operate similar to venetian blinds
  - Not efficient as other shutters
  - Shadows created by open louver cause uneven lighting over focal plane

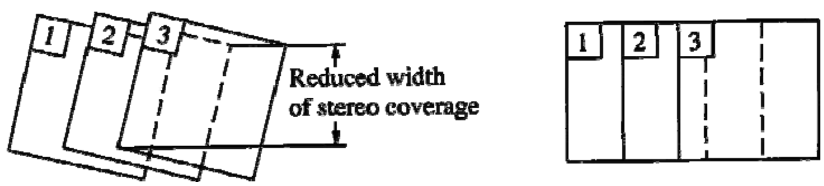
# CAMERA MOUNTS

- Attaches camera to aircraft
- Constrains angular alignment of camera
- Minimum mount has dampener devices & crab correction
- Crab
  - Difference in camera orientation w.r.t. aircraft's actual travel direction



# EFFECT OF CRAB

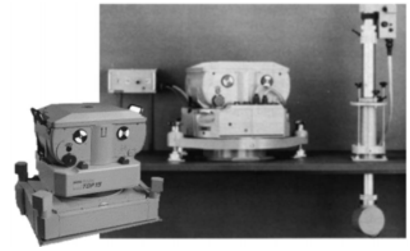
- Undesirable effect – reducing stereoscopic ground coverage of aerial photos




# CAMERA MOUNTS

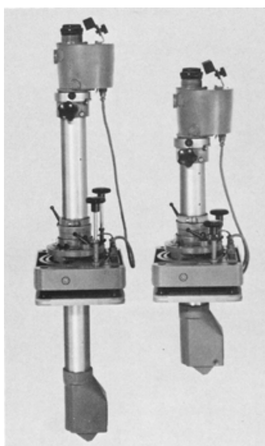

- More elaborate mounts provide gyro stabilization of camera
  - Gyroscopic devices sense rotational movement of aircraft
  - Movements applied to camera to keep it properly oriented through microprocessor-controlled motors
  - Rotations can be measured and recorded also

# CAMERA CONTROLS

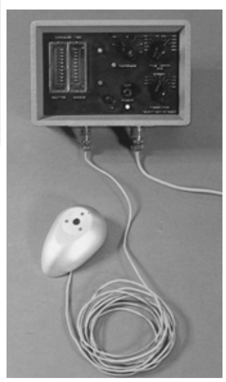


- Intervalometer
  - Device that automatically trips shutters & activates camera cycle
  - Interval depends on focal length, format size, end lap, flying height, velocity
  - Modern intervalometers – part of integrated unit incorporating GPS

# CAMERA CONTROLS

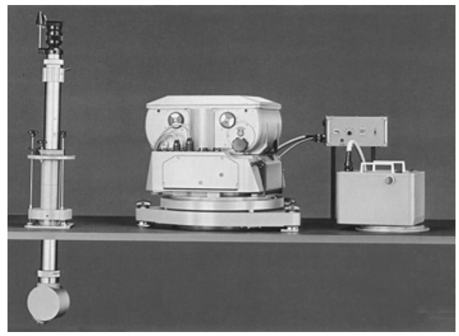


- Viewfinder
  - Can view the terrain beneath the aircraft and to see the ground coverage of each photo
- Exposure control
  - Exposure meter that measures terrain brightness



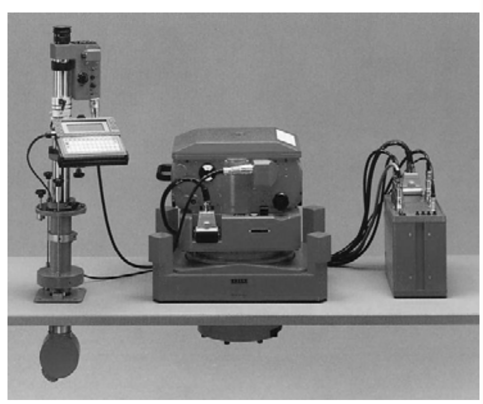
## ZEISS RMK A 15/23 WIDE-ANGLE CAMERA

- With ICC/NS-1Central Interval Computer and NT-1 Navigation Telescope
- Pleogon A (153 mm) lens, 93º angular field of view, Max nominal distortion 2 μm
- Used for general work
  - Aerotriangulation, topographic and large-scale mapping



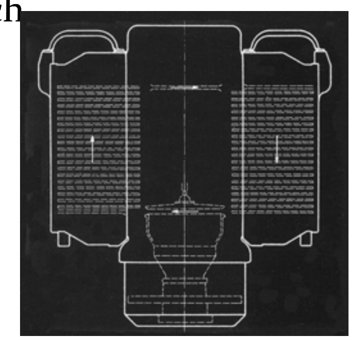
## ZEISS RMK TOP 15 AERIAL CAMERA

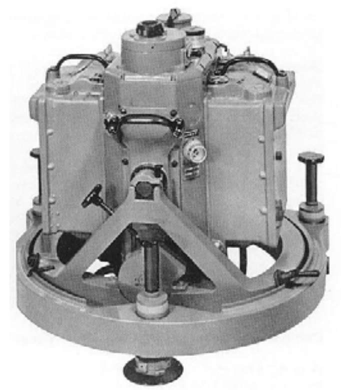
- Pleogon A 3 wide-angle lens, focal length = 153 mm
- Distortion ±3 μm max.
- Pulsed rotating-disk shutter
- 8 numbered, point-shaped fiducials
- FMC 0-64 mm/s
- TA-S gyro-stabilized suspension mount
  - Stabilized in φ & ω ± 5º
  - Additional control in κ ± 30º



## WILD RC 7 a AUTOMATIC PLATE CAMERA

- Available with 2 lens cones: normal and wide angle
- Two symmetrically arranged magazines contain 40 plates each





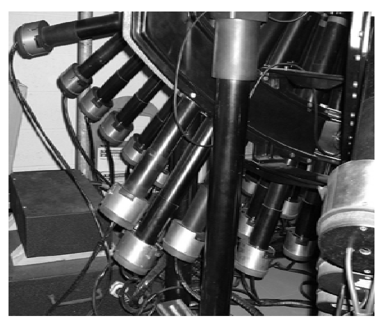
## WILD RC 10

- Rotary shutter between lens
- Electric vacuum pump with automatic regulator value for film flattening
- Film spools housed in its own individual cassette

# LEICA RC 30

- Shown with gyro-stabilized mount and on-board ASCOT computer
- High quality lens
- Long-term stability
- FMC
- Gyro-stabilized mount
- Automatic exposure meter
- Communications with other systems & ASCOT
- Data annotation on each photo
- Modular design, microprocessor controlled

# CALIBRATION



- Assignment of numbers to represent properties that describe the metric characteristics of the measurement system and describe the quality of the performance
  - Concepts
    - Component concept – assess quality of different components within photogrammetric process
    - System concept – take into consideration the whole photogrammetric process

## CALIBRATION

- Classes
  - Laboratory – outgrowth of manufacturers
    - Visual approach – optical goniometers
    - Photographic approach – bank of optical collimators
  - Field
    - Horizon method – only horizontal angles measured
    - Full field method – horizontal & vertical angles measured
    - Stellar method – use star field as control
  - System – results in measurement system from which comparisons can be made
    - Prepare system specifications by precisely defining the measurement system
    - Exercise system by comparing results to known values of higher quality and assess the results

## OPTICAL GONIOMETER

- Center precise grid plate in camera focal plane
- Grid illuminated from rear and projected through cameral lens
- Angles to projected grid rays emerging from lens measured with a goniometer

## CAMERA CALIBRATION

- Determine precise & accurate values for elements of interior orientation
  - Calibrated focal length (CFL)
    - Focal length producing mean distribution of lens distortion
    - Really a calibrated principal distance
  - Symmetric radial lens distortion
    - Occurs along radial lines from principal point
  - Decentering lens distortion
    - Further broken into asymmetric radial and tangential
    - Caused by manufacture imperfections and lens alignment

## CAMERA CALIBRATION

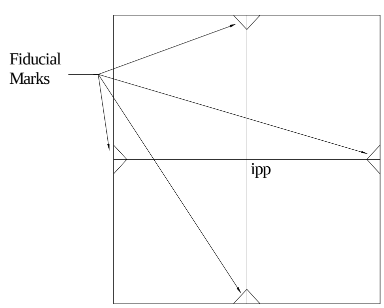
- Principal point location
  - x-, y-coordinates of principal point wrt the fiducial marks
- Fiducial mark coordinates
  - Provide 2-D positional reference for principal point as well as images on the photo
- Resolution
  - Sharpness or crispness
  - Highest near center
- Focal plane flatness
  - Deviation of platen from true plane
- Shutter efficiency
  - Ability to operate correctly

# FOCAL LENGTH

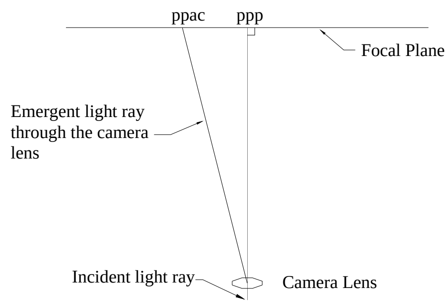
- Nominal
  - focal length classification
- Equivalent (EFL)
  - Effective focal length near center of camera lens
- Calibrated (CFL)
  - Also called camera constant
  - Adjusted value of EFL – distribute lens distortion over entire field of camera

# PRINCIPAL POINTS

- Indicated principal point (ipp)
  - “fiducial center” or “center of collimation”
  - Intersection of opposite fiducials
- Principal point of geometric optics (ppgo)
  - Point on optical axis at which the optical axis intersects the principal plane



## PRINCIPAL POINTS



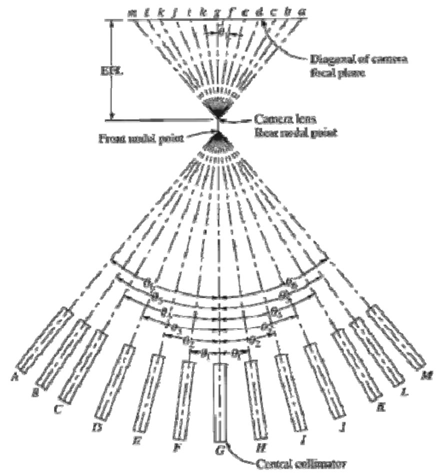

- Principal point of photogrammetry (ppp)
  - Foot of perpendicular from the interior perspective center to the plane of the photograph
- Principal point of autocollimation (ppac)
  - Intersection point of a ray with the plane of the photo for that ray which is perpendicular to the focal plane prior to passing through the lens

## PRINCIPAL POINTS

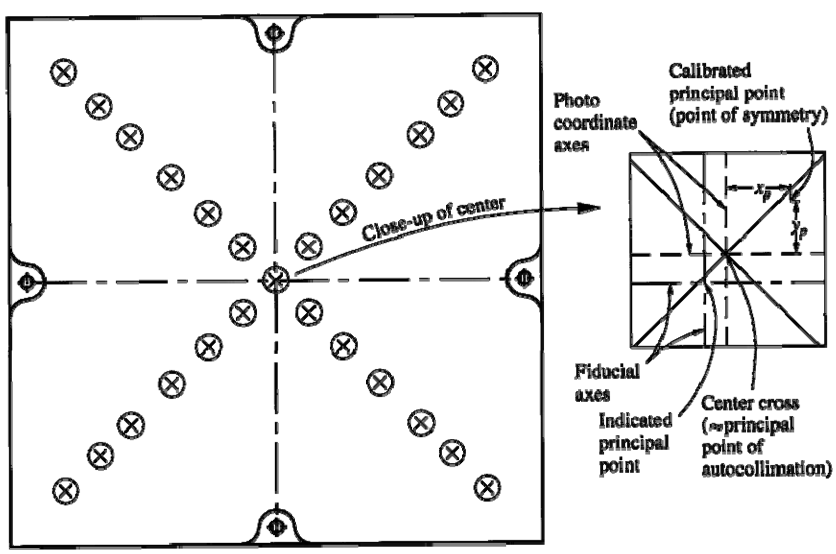
- Principal point of symmetry (pps)
  - "calibrated principal point"
  - Point in focal plane about which all lens distortion are most nearly symmetrical
  - Can only be approximated when decentering distortion is present
- Principal point of minimum variance (ppmv)
  - Numerical values adopted for the photo origins in terms of fiducial centered coordinates usually resulting from a least squares adjustment

# COLLIMATOR METHOD

- Photograph images projected through a number of individual collimators mounted in precisely measured angular array
- Collimator is a lens with a cross mounted on its plane of infinite focus



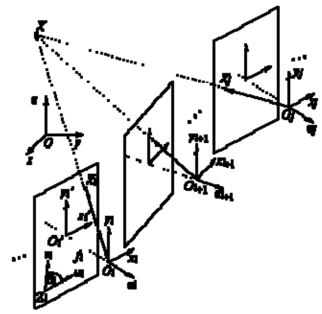

# COLLIMATOR METHOD



## CAMERA CALIBRATION

Simple approach to calibration

- Compute equivalent focal length

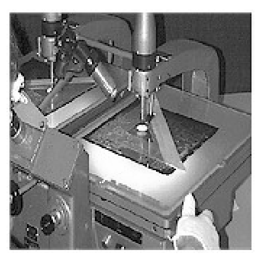


$$EFL = \frac{s_{7.5^o}}{\tan 7.5^o}$$

  - s = measured distance from principal point to collimator target
  - $\alpha$ = angle from principal point to collimator target

## CAMERA CALIBRATION

- Compute diagonals to the other crosses



$$s'_i = EFL \tan \theta_i$$

  - where i = 15$^O$, 22.5$^O$, 30$^O$, 37.5$^O$, 45$^O$,

- Compute distortions at each point

$$d_i = s_i - s'_i = s_i - EFL \tan \theta_i$$

# CAMERA CALIBRATION

- Calibrated focal length one which makes the maximum positive distortion equal to the maximum negative distortion

$$\left\{ s_1 - CFL \tan \theta_1 \right\} + \left\{ s_2 - CFL \tan \theta_2 \right\} = 0$$

$$s_1 + s_2 = CFL \left( \tan \theta_1 + \tan \theta_2 \right)$$

$$CFL = \frac{s_1 + s_2}{\tan \theta_1 + \tan \theta_2}$$

# CAMERA CALIBRATION

Example: Given the following data from collimator observations

| Angular Value (degrees) | Measured Value (mm) |
|---|---|
| 7.5 | 20.223 |
| 15.0 | 41.177 |
| 22.5 | 63.663 |
| 30.0 | 88.726 |
| 37.5 | 117.866 |
| 45.0 | 153.435 |

# CAMERA CALIBRATION

Solution

$$EFL = \frac{s_{7.5^o}}{\tan 7.5^o} = \frac{20.223\,mm}{\tan 7.5^o} = 153.609\,mm$$

$$d_{15^o} = 41.177\,mm - (153.609\,mm)\tan 15^o = +0.018\,mm$$
$$d_{22.5^o} = 63.663\,mm - (153.609\,mm)\tan 22.5^o = +0.036\,mm$$
$$d_{30^o} = 88.726\,mm - (153.609\,mm)\tan 30^o = +0.040\,mm$$
$$d_{37.5^o} = 117.866\,mm - (153.609\,mm)\tan 37.5^o = -0.002\,mm$$
$$d_{45^o} = 153.435\,mm - (153.609\,mm)\tan 45^o = -0.174\,mm$$

# CAMERA CALIBRATION

Solution

$$CFL = \frac{s_1 + s_2}{\tan\alpha_1 + \tan\alpha_2} = \frac{88.726\,mm + 153.435\,mm}{\tan 30^o + \tan 45^o} = 153.524\,mm$$

$$d_{7.5^o} = 20.223\,mm - (153.524\,mm)\tan 7.5^o = +0.011\,mm$$
$$d_{15^o} = 41.177\,mm - (153.524\,mm)\tan 15^o = +0.040\,mm$$
$$d_{22.5^o} = 63.663\,mm - (153.524\,mm)\tan 22.5^o = +0.071\,mm$$
$$d_{30^o} = 88.726\,mm - (153.524\,mm)\tan 30^o = +0.089\,mm$$
$$d_{37.5^o} = 117.866\,mm - (153.524\,mm)\tan 37.5^o = +0.063\,mm$$
$$d_{45^o} = 153.435\,mm - (153.524\,mm)\tan 45^o = -0.089\,mm$$

# USGS CAMERA CALIBRATION

- Simultaneous Multi-Camera Analytical Calibration (SMAC) – current model
  - Least squares version of photogrammetric resection
  - Plate coordinates – observed values
  - Collimator directions – known coordinates
  - Adjust interior perspective center & camera orientation to minimize differences
  - Result: calibrated focal length, profile of mean radial distortion, coordinates of principal point

# SMAC MATH MODEL

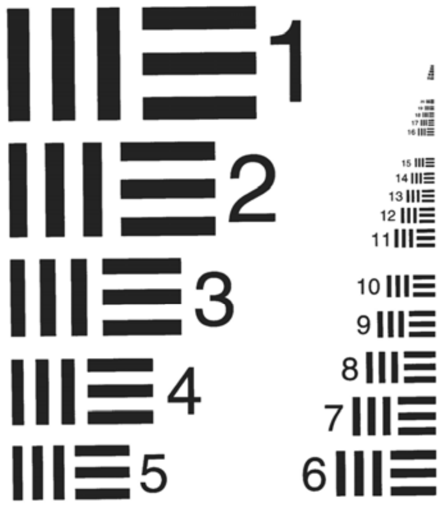
$$x - x_P = \underbrace{f\left[\frac{A\lambda + B\mu + C\upsilon}{D\lambda + E\mu + F\upsilon}\right]}_{\text{Projective Equation}} + \underbrace{x\left[K_1 r^2 + K_2 r^4 + K_3 r^6\right]}_{\text{Radial Distortion}}$$

$$+ \underbrace{\left[1 + P_3^2 r^2\right]\left[P_1\left(r^3 + 2x^2\right) + 2P_2 xy\right]}_{\text{Decentering Distortion}}$$

$$y - y_P = f\left[\frac{A\lambda + B\mu + C\upsilon}{D\lambda + E\mu + F\upsilon}\right] + y\left[K_1 r^2 + K_2 r^4 + K_3 r^6\right]$$

$$+ \left[1 + P_3^2 r^2\right]\left[2P_1 xy + P_2\left(r^3 + 2y^2\right)\right]$$

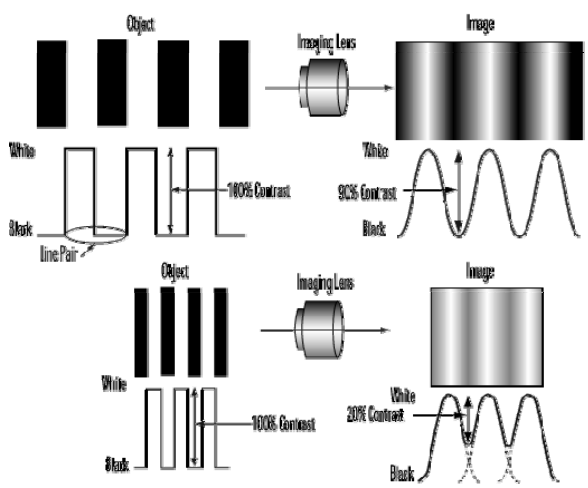
## LINE COUNT METHOD




- Photograph resolution test pattern
- Images examined under magnification
- Find finest set of parallel lines discernable
- Area Weighted Average Resolution (AWAR)
  - Resolution over entire format

## MODULATION TRANSFER FUNCTION

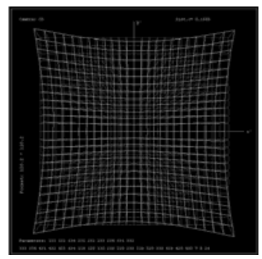
- Spatial frequency is fundamental concept
- Measure of number of cycles of a sinusoidal wave per unit distance



## DIGITAL IMAGING DEVICES

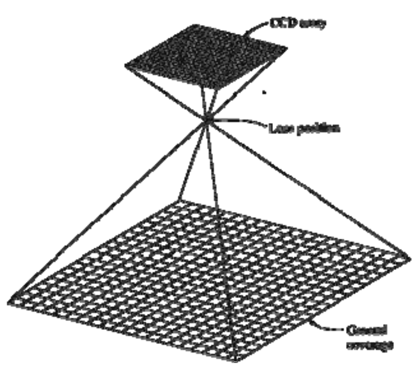
- Rectangular array of pixels
  - Brightness quantifies at discrete locations
  - Use solid state detectors to sense energy
    - Most common – CCD
    - Element exposed to incident energy, builds up electric charge proportional to incident light
    - Electric charge amplified and converted to digital form

UltraCamX Large Format Digital Aerial Camera



## DIGITAL FRAME CAMERA

- 2-D array of CCD elements
  - Full-frame sensor
- Sensor mounted in focal plane of single-lens camera
- Classified by number of pixels in image
  - Inexpensive digital cameras 500 rows & 500 columns for 250,000 pixels
  - Megapixel arrays have at least 1 million pixels (ex 1034 x 1024)



## DIGITAL FRAME CAMERA CALIBRATION

- CCD elements essentially fixed in position
- Initially, each pixel assumed to be in perfect grid
  - Calibrate using two-dimensional transformation
- Upper limit of resolution absolutely fixed
  - Sampling into discrete elements
  - Maximum spatial frequency:
    - w = width between centers
    - $f_{MAX}$ = max detectable frequency

$$f_{MAX} = \frac{1}{2w}$$

## DIGITAL FRAME CAMERA

- Example (3-2): Digital frame camera consists of 5120 x 5120 pixel array. Pixel size = 12 μm. Nominal focal length = 40 mm.
  - What is maximum spatial frequency that can be detected (at image scale)?
  - What is the angular field of view for this camera?

## DIGITAL FRAME CAMERA EXAMPLE

- Maximum spatial frequency

$$f_{MAX} = \frac{1}{2w} = \frac{1}{2(0.012\,\text{mm})} = 42\ \text{cycles/mm}$$

- Diagonal distance d

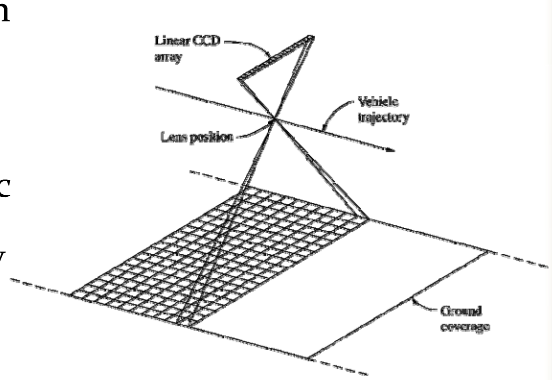
$$d = \sqrt{(5120 \cdot 0.012\,\text{mm})^2 + (5120 \cdot 0.012\,\text{mm})^2} = 87\,\text{mm}$$

- Angular field of view

$$\alpha = 2\tan^{-1}\left(\frac{d}{2f}\right) = 2\tan^{-1}\left(\frac{87\,\text{mm}}{2 \cdot 40\,\text{mm}}\right) = 95^{o}$$

## LINEAR ARRAY SENSORS

- Strip of CCD elements mounted in focal plane
- Geometry called line perspective
- For photogrammetric purposes, vehicle must travel smoothly
  - Tips & tilts result in distortions
  - Used in satellite platforms



# LINEAR ARRAY SENSORS

- Satellite linear array sensor travels at 7300 m/s. Pixel size = 10.0m at ground scale. At what rate (in hertz) must the detector be read in order to produce the image?
- Time interval, Δt, required to travel width of 1 pixel

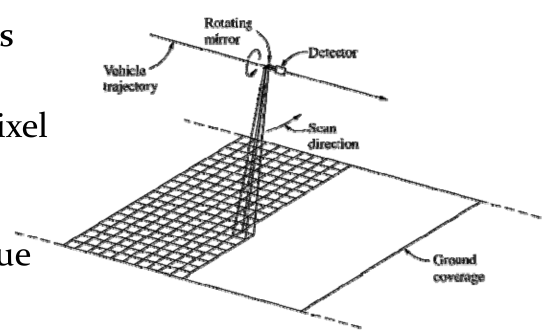
$$\Delta t = \frac{10.0\,\text{m}}{7300\,\text{m/s}} = 0.0014\,\text{s}$$

- Sample rate, r, is reciprocal of Δt

$$r = \frac{1}{0.0014\,\text{s}} = 730\,\text{s}^{-1} = 730\,\text{Hz}$$

# FLYING SPOT SCANNER

- Commonly use mirror that oscillates transverse to vehicles trajectory
- Image formed one pixel at a time
- Scan lines actually skewed somewhat due to forward motion
- Geometric stability even more important

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