CHAPTER THREE

PHOTOGRAPHIC SENSORS

INTRODUCTION

- Photography means "to write with light"
  - Today's meaning is often expanded to include radiation just outside the visible spectrum, i. e. ultraviolet and near infrared (NIR) regions
- Photography is the most practical, inexpensive, and widely used for remote sensing
- The basic optical principals used for photography are also used in optical systems involving nonphographic sensors by using photographic film

INTRODUCTION (CONT'D)

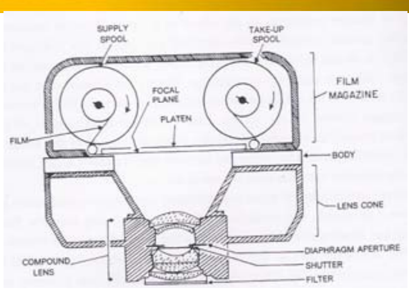
- Evolution:
  - In antiquity, Greek and Arab scholars knew that images could be formed as light passes through a pinhole opening in dark enclosure
  - In medieval Europe, a device known as the camera obscura ("dark chamber") employed this principle to project an image onto a screen as an aid for artists, who could then trace the outline of the images as the foundation for maore elaborate drawings or paintings
  - During the Renaissance, the addition of a simple convex lens improved the camera obscura, although there was still no convenience means of recording the image formed on the screen
  - With the development of photographic emulsions as a means of making a detailed record of the image, the camera obscura began its evolution towards the everyday cameras that we know today, which in turns are models for the more complex cameras used for aerial survey

THE AERIAL CAMERA

The main components:

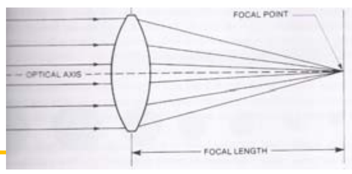
- A lens to focus light on the film
- A light-sensitive film to record the image
- A shutter that controls entry of light in to the camera
- The camera body
- Film magazine
- Drive mechanism
- Lens cone

THE AERIAL CAMERA (CONT'D)



THE AERIAL CAMERA: LENS

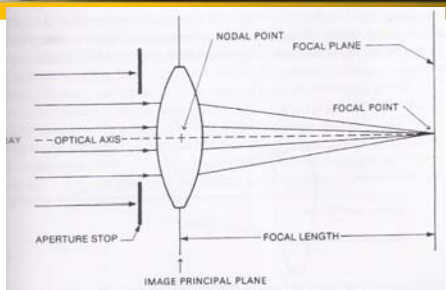
- The main task: to gather reflected light and focuses it on the film
- Imperfections in lens shape contribute to spherical aberrations, a source of error that distorts images and causes loss of image clarity
- For modern aerial photography, spherical aberration is usually not a severe problem because most modern aerial cameras use lenses of very high quality



THE AERIAL CAMERA: LENS

- Most aerial cameras use compound lenses, formed from many separate lenses of varied sizes, shapes, and properties.
- Why? To correct for the errors that may be present in any single component, so the whole unit is much more accurate than any single element.
- Lens properties:
  - Optical axis
  - Image principle plane
  - Nodal point
  - Focal point
  - Focal plane
  - Focal length

THE AERIAL CAMERA: LENS



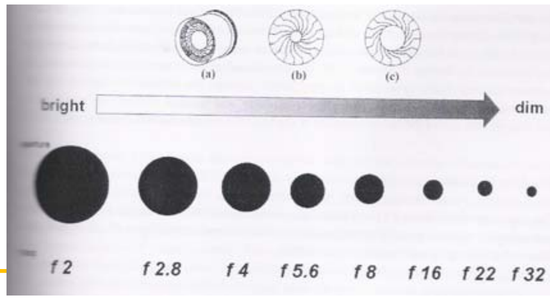
THE AERIAL CAMERA: LENS

- The field of view of a lens can be controlled by a field stop, a mask positioned just in front of the focal plane
- The aperture stop is usually positioned near the center of a compound lens; it consists of a mask with a circular opening of adjustable diameter
- An aperture stop can control the intensity of light at the focal plane, but does not influence the field of view or the size of the image
- Manipulation of the aperture stop controls only the brightness of the image without changing its size
- Usually aperture size is measured as the diameter of the adjustable opening that admits light to the camera

$$f = \text{focal length}/\text{aperture size}$$

$$f = \text{f-number or relative aperture}$$

THE AERIAL CAMERA: LENS



THE AERIAL CAMERA: The Shutters

- Controls the length of time that the film is exposed to light
- The simplest shutters are often metal blades positioned between elements of the lens, forming “intralens” or “between-the-lens” shutters
- Alternative lens form of shutters is the focal plane shutter, consisting of a metal or fabric curtain positioned just in front of the film, near the focal plane

THE AERIAL CAMERA: The Film Magazine

- Is a light-tight container that holds the supply of film
- Usually includes
  - A supply spool, holding perhaps several hundred feet of unexposed aerial film
  - A take-up spool to accept exposed film

THE AERIAL CAMERA: The Lens Cone

- Supports the lens and filters and holds them in their correct positions in relation to the film
- Common focal lengths for typical aerial cameras are 150 mm, 300 mm, and 450 mm

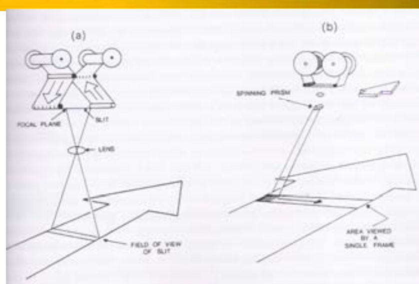
THE AERIAL CAMERA: The Drive Mechanism

- The drive mechanism advances the film after each exposure, using electric motors activated in coordination with the shutter and the motion of the plane
- At the time exposure the film must lie flat in the camera's focal plane
- The function is performed by the platen, a small, spring-mounted, metal plate positioned to hold the film flat at the instant of exposure
- Special platen: vacuum platen, consists of a flat plate positioned at the focal plane; a vacuum pump draws air through small holes in the plate to hold the film flat and stationary during exposure
- High-quality aerial cameras usually include image motion compensation capability, mechanism that moves the film platen during exposure at a speed and in direction that compensates for the apparent motion of the image in the focal plane

KINDS OF AERIAL CAMERAS

- Reconnaissance cameras
  - For military use
- Strip cameras
  - Acquiring images by moving film past a fixed slit that serves as a form of shutter
- Panoramic cameras
  - Designed to record a very wide field of view

KINDS OF AERIAL CAMERAS

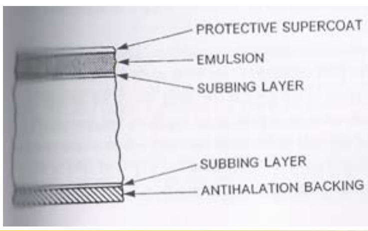


BLACK AND WHITE AERIAL FILMS

- Evolutions:
  - In late 1700s and early 1800s using light-sensitive (photosensitive) chemicals, e.g. silver nitrate ($AgNO_3$)
  - J. N. Niepce invented the first negative image
  - Niepce and Daguerre designed a silver-coated metal plate treated with iodine vapor
  - Daguerrotypes, an early name for photographic images made using Daguerre's method
  - In the 1800s equipment was large, heavy, and cumbersome
  - G. Eastman invented roll film and standardized methods of photographic processing
  - In 1888, invention of the Kodak camera and formation of the Eastman Kodak Company

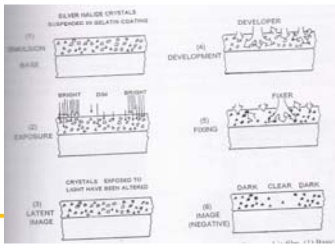
BLACK AND WHITE AERIAL FILMS

- Major components: schematic cross-sectional view of black-and-white photographic film



BLACK AND WHITE AERIAL FILMS

Development is the process of bathing the exposed film in an alkaline chemical (the developer) that reduces the silver halide grains that have been exposed to the light.



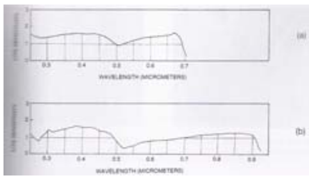
BLACK AND WHITE AERIAL FILMS

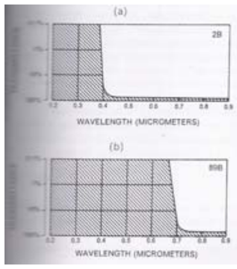
- A fixer is applied to dissolve, then remove, unexposed silver halide grains
- After development and fixing, the resulting image is a negative representation of the scene, because those areas that were brightest in the scene are represented by the greatest concentrations of metallic silver, which appears dark on the processed image

BLACK AND WHITE AERIAL FILMS

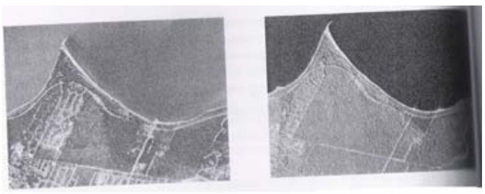
- Film speed is a measure of the sensitivity of an emulsion to light
- Contrast indicates the range of gray tones recorded by a film
  - High contrast means the film records the scene largely in blacks and whites, with few intermediate gray tones
  - Low contrast indicates a representation largely in grays, with few really dark or really dark tones
- Spectral sensitivity records the special region to which a film is sensitive

BLACK AND WHITE AERIAL FILMS





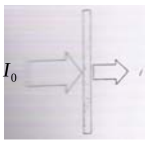
BLACK AND WHITE AERIAL FILMS



Left: panchromatic film
Right: Black and white infrared film

BLACK AND WHITE AERIAL FILMS

- Opacity (darkness of a region): the ratio between light intensity I_0 and the brightness measured on the other side I



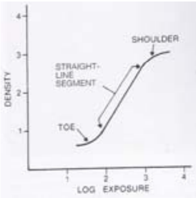
$$\text{opacity} = I_0 / I$$

$$E = i \times t$$

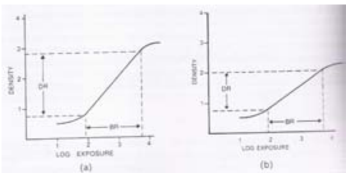
time

intensity

BLACK AND WHITE AERIAL FILMS



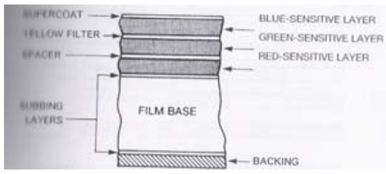
Characteristic curve of a photographic emulsion



BRIGHTNESS RANGE

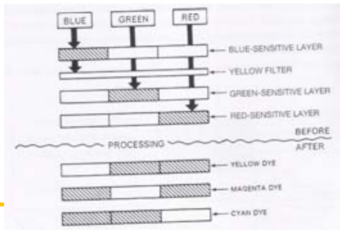
COLOR REVERSAL FILMS

- Many of color films used in remote sensing are reversal films, similar to those used in hand-held cameras for color slides



COLOR INFRARED FILMS

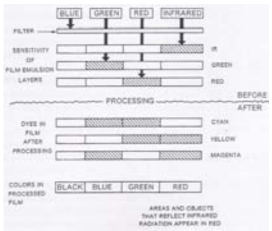
- Based on the same principles as color reversal films except for differences in the sensitivity of the emulsions and conventions in representation of colors

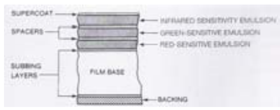


Color representation in color reversal film

COLOR INFRARED FILMS

Color representation in color infrared film





COLOR INFRARED FILMS

The comparison with normal color films can be represented as follows:

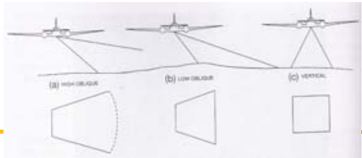
Object in the scene reflects	Blue	Green	Red	Infrared
Color reversal film represents the object as	Blue	Green	Red	*****
Color infrared film represents the object as	****	Blue	Green	Red

FILM FORMAT AND ANNOTATION

- Format: designing the size of the image acquired by a camera
- Common format: 23 cm x 23 cm and 5.7 cm x 5.7 cm
- Special purpose format: 24 mm x 36 mm
- In some instances, paper prints are not made, and the film is examined simply as a strip of a film – a positive transparency – wound on large spools and viewed against an illuminated backgrounds
- Most aerial photographs carry some annotation, marking that identify the photographs and provide details concerning their acquisition.
- Annotation consists of a series of letters and numerals that can vary in meaning from one aerial survey firm to the next, but usually they include the date of the photography, a series of letters and numbers that identify each project, and the film roll number. Image scale maybe included.

GEOMETRY OF THE VERTICAL AERIAL PHOTOGRAPH

- Aerial photograph can be classified according to the orientation of the camera in relation to the ground at the time of exposure
- Oblique aerial photographs have been acquired by cameras oriented toward the side of the aircraft
  - High oblique photographs show the horizon
  - Low oblique photographs are acquired with the camera aimed more directly toward the ground



GEOMETRY OF THE VERTICAL AERIAL PHOTOGRAPH

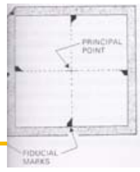
High Oblique photograph

GEOMETRY OF THE VERTICAL AERIAL PHOTOGRAPH

- Vertical photographs are acquired by a camera aimed directly at the ground surface from above

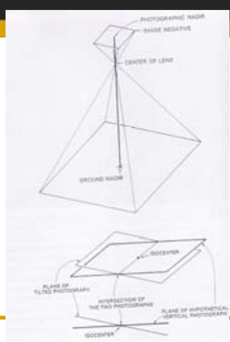
GEOMETRY OF THE VERTICAL AERIAL PHOTOGRAPH

- Aerial cameras are manufactured to include adjustable index marks attached rigidly to the camera so that the positions of the index marks are recorded on the photograph
- These fiducial marks (usually four or eight in number) appear as silhouettes at the edges and/or corners of the photograph
- Lines that connect opposite pairs of fiducial marks intersect to identify the principal point



GEOMETRY OF THE VERTICAL AERIAL PHOTOGRAPH

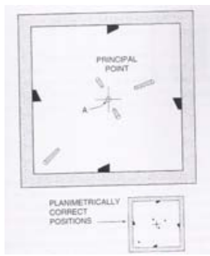
- The ground nadir: the point on the ground vertically beneath the center of the camera lens at the time the photograph was taken.
- The photograph nadir: the intersection with the photograph of the vertical line that intersects the ground nadir and the center of the lens
- Isocenter: the focus of tilt



GEOMETRY OF THE VERTICAL AERIAL PHOTOGRAPH

The most important positional errors in the vertical aerial photograph:

1. Optical distortions: errors caused by an inferior camera lens, camera malfunction, etc.
2. Tilt is caused by displacement of the focal plane from a truly horizontal position by aircraft motion
3. Because of routine use of high-quality cameras and careful inspection of photography to monitor photo quality, today the most important source of positional error in vertical aerial photography is probably relief displacement



COVERAGE BY MULTIPLE PHOTOGRAPH

- Pilots normally acquire vertical aerial photographs by flying series of parallel flight lines that together build up complete coverage of a specific region
- Each flight line consists of individual frames, usually numbered in sequence
- If the plane's course is deflected by a crosswind, the positions pf ground areas shown by successive photographs form the pattern shown, known as drift
- Crab is caused by correction of the flight path to compensate for drift without a change in the orientation of the camera
- Usually flight plans call for a certain amount of forward overlap, duplicate coverage by successive frames in a flight line, usually by about 50-60%

COVERAGE BY MULTIPLE PHOTOGRAPH

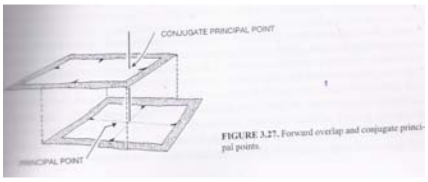
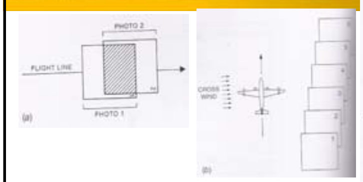
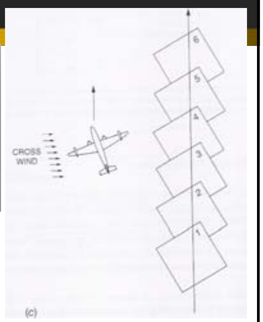


FIGURE 3.27. Forward overlap and conjugate principal points.

COVERAGE BY MULTIPLE PHOTOGRAPH



Aerial photographic coverage: (a) forward overlap, (b) drift, and



COVERAGE BY MULTIPLE PHOTOGRAPH

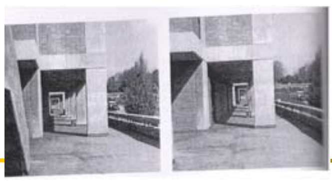
- When it is necessary to photograph large areas, coverage is built up by means of several parallel strips of photography; each strip is called a flight line

$$\text{Number of photos} = \frac{\text{length of flight line}}{(gd \text{ of photo}) \times (1 - \text{overlap})}$$

gd = ground distance represented on a single frame
measured in the same units as the length of the planned flight line

Stereoscopic Parallax

- If we have two photographs of the same area taken from different camera positions, we observe a displacement of images of objects from one image to the other
- This difference in appearances of objects due to change in perspective is known as stereoscopic parallax

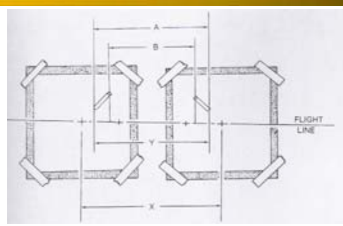


Stereoscopic Parallax

Measurement of stereoscopic parallax

$$h = \frac{H \times dp}{p + dp}$$

H = flying height of aircraft
dp = differential parallax = A – B
P = X – Y
h = height of the object



MOSAICS

- A series of vertical aerial photographs that show adjacent regions on the ground can be joined together to form a mosaic
- Aerial mosaic belong one of two classes:
  - Uncontrolled mosaics, formed by placing the photographs together in a manner that provides continuous coverage of an area, without concern for preservation of consistent scale and positional relationship
  - Controlled mosaics, formed from individual photographs assembled in a manner that preserves correct positional relationships between the features they represent

MOSAIC

Uncontrolled mosaic

ORTHOPHOTOS AND ORTHOPHOTOMAPS

- Aerial photographs are not planimetric maps because they have geometric errors, most notably the effects of relief displacement, in the representations of the features they show
- Stereoscopic photographs can be used to generate a corrected form of an aerial photograph known as an orthophoto that shows photographic detail without the errors caused by tilt and relief displacement
- Orthophotomaps can be used for most purposes as maps because they show correct planimetric position and preserve consistent scale throughout the image
- Orthophotograph form the basis for orthophotomaps, which are orthophotographs presented in map format, with annotations, scale, and geographic coordinates.

DIGITAL ORTHOPHOTO QUADRANGLES

- Digital orthophoto quadrangles (DOQs) are orthophotos prepared in a digital format, designed to correspond to 7.5-minute quadrangle of the U.S. Geological Survey (USGS)
- DOQs are presented either as black-and-white or as color images that have been processed to attain the geometric properties of a planimetric map

DIGITAL ORTHOPHOTO QUADRANGLES

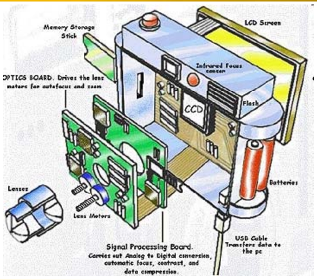
DIGITAL PHOTOGRAPHY

- Photograph can be electronically scanned to record the patterns of blacks, grays, and whites as digital values, each representing the brightness of a specific point within the image

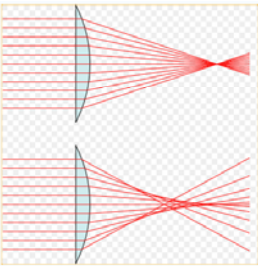
TERMINOLOGY

- Exposure
  Refers to a single shutter cycle
- Alkaline
  Also known as alkali, a basic, ionic salt of an alkali metal
- Panchromatic film
  An emulsion that is sensitive to radiation throughout the visible spectrum
- Planimetric
  A two-dimensional representation of geographical space

CAMERA



SPHERICAL ABBERATIONS



F STOP

f/32 - narrow aperture and slow shutter speed

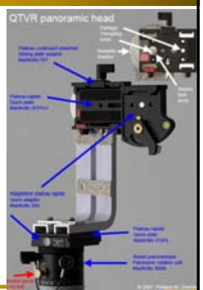
f/5.6 - wide aperture and fast shutter speed

PLATEN

KINDS OF CAMERAS

Reconnaissance camera

Strip camera



Panoramic camera