Digital Photogrammetry

Unit 1 Development of digital photogrammetry
digital photogrammetry: Components: hardware – software
Data acquisition: Scanners - Platforms: Aircrafts – UAV – satellites (*CARTOSAT, GEOEYE, WORLDVIEW, Kompsat-3, Pléiades-HR)*

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UAV Platforms Photogrammetry

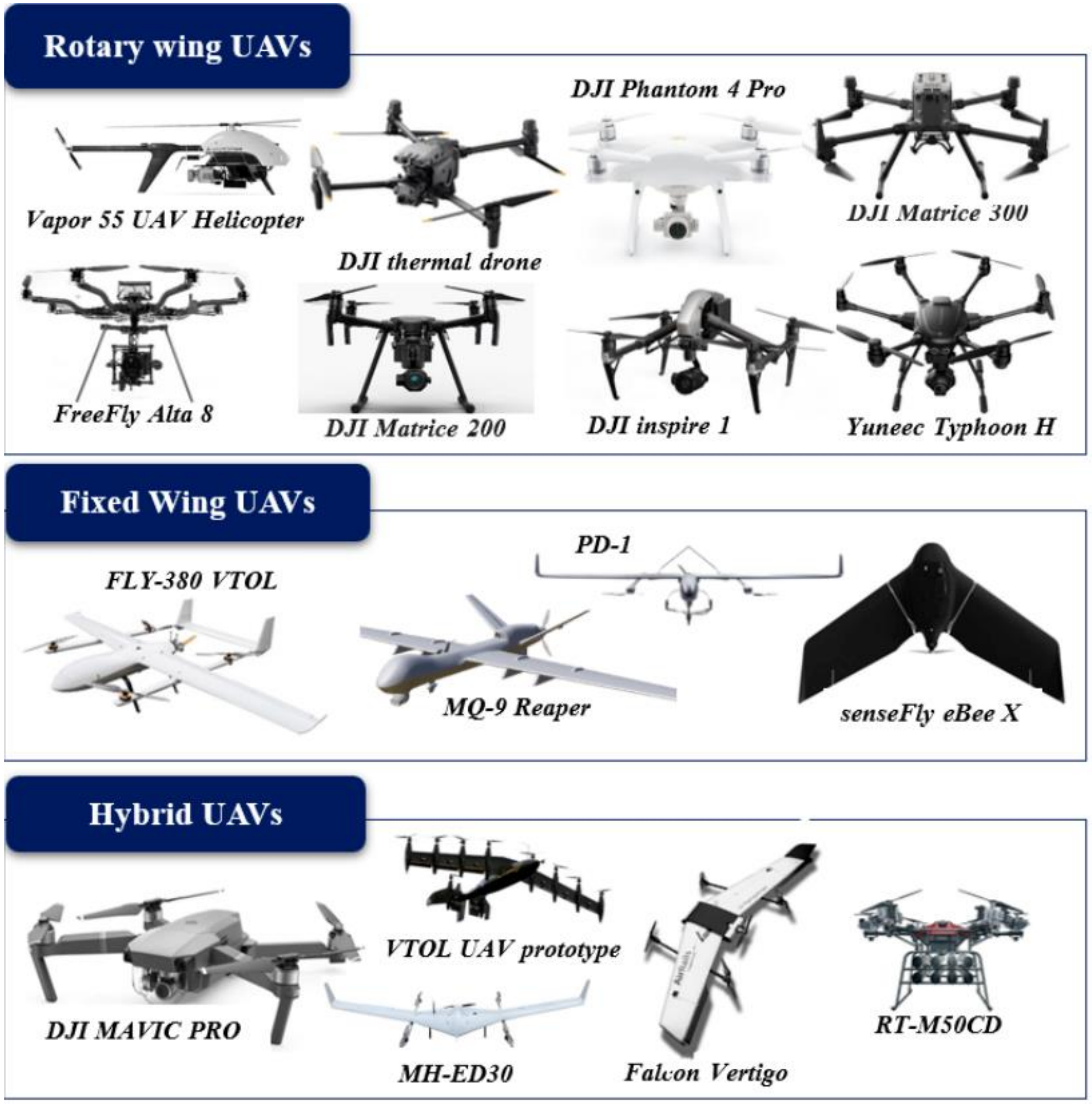
What is a Drone?

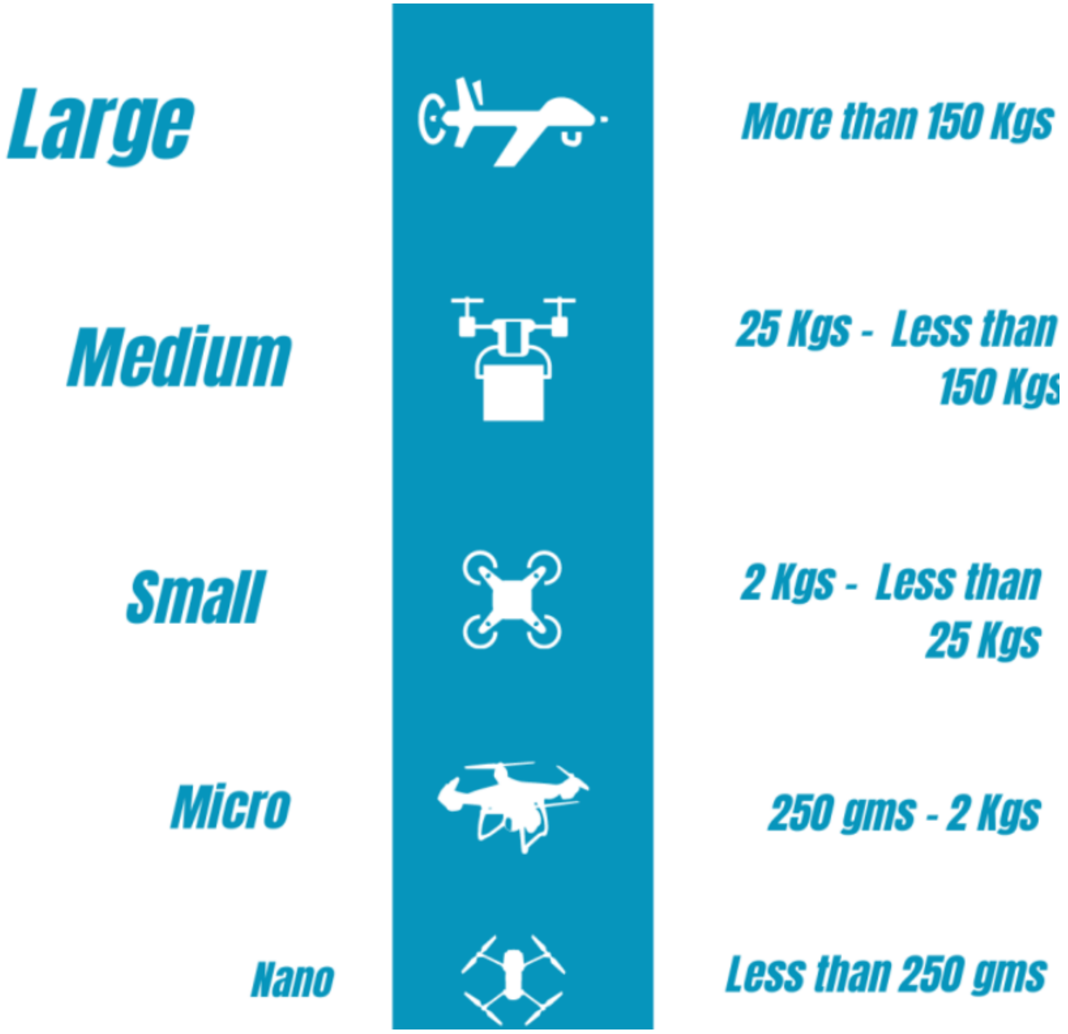
A drone is an unmanned aerial vehicle (UAV) or unmanned aircraft system. It is essentially a flying robot this is controlled remotely or can fly autonomously with software-controlled flight plans embedded in its system that work in conjunction with sensors and a global positioning system (GPS). Drones are of different types and sizes and are used for a variety of purposes.

Types of Drones

- Multi-Rotor Drones
- Fixed-Wing Drones

https://www.auav.com.au/articles/drone-types/#1





https://www.researchgate.net/figure/Different-categories-of-frequently-used-UAV-models-in-bushfire-management_fig4_367023246

https://www.zentechnologies.com/blog/wp-content/uploads/2022/06/drone-types.png

Types of Drone Classified by Government of India

- **Nano Drone** - Less than or equal to 250 gm
- **Micro Drone** - More than 250 gm - Up to 2 kg
- **Small Drone** - More than 2 kg - Up to 25 kg
- **Medium Drone** - More than 25 kg - Up to 150 kg
- **Large Drone** - More than 150 kg

https://static.pib.gov.in/writereaddata/specificdocs/documents/2022/jan/doc202212810701.pdf

1. Multi-Rotor Drones

Advantages:

- ❖ It provides better control of the aircraft during the flight.
- ❖ Due to its increased maneuverability, it can move up and down on the same vertical line, back to front, side to side and rotate in its own axis.
- ❖ It has the ability to fly much more closely to structures and buildings.
- ❖ The ability to take multiple payloads per flight increases its operational efficiency and reduces the time taken for inspections.

Disadvantages:

- ❖ Multi-rotor drones have limited endurance and speed, making them unsuitable for large scale aerial mapping, long-endurance monitoring and long-distance inspection such as pipelines, roads and power lines.
- ❖ They are fundamentally very inefficient and require a lot of energy just to fight gravity and keep them in the air.
- ❖ With the current battery technology, they are limited to around 20-30 minutes when carrying a lightweight camera payload. However, heavy-lift multi-rotors are capable of carrying more weight, but in exchange for much shorter flight times.
- ❖ Due to the need for fast and high-precision throttle changes to keep them stabilized, it isn't practical to use a gas engine to power multi-rotors, so they are restricted to electric motors. So, until a new power source comes along, we can only expect very small gains in flight time.

https://www.auav.com.au/articles/drone-types/#1

2. Fixed-Wing Drones

A fixed-wing drone has one rigid wing that is designed to look and work like an aero plane, providing the lift rather than vertical lift rotors. Hence, this drone type only needs the energy to move forward and not to hold itself in the air. This makes them energy-efficient

Advantages:

•Fixed-wing drones cover longer distances, map much larger areas, and loiter for long times monitoring their point of interest. The average flight time is a couple of hours. But with a greater energy density of fuel (gas engine powered), many fixed-wing UAVs can stay aloft for 16 hours or more.

•This drone type can fly at a high altitude, carry more weight and are more forgiving in the air than other drone types.

Disadvantages:

•Fixed-wing drones can be expensive.

•Training is usually required to fly fixed-wing drones. The first time you launch a fixed-wing drone, you need to be confident in your abilities to control through the flight and back to a soft landing. A fixed-wing drone is always moving forward, and they move a lot quicker than a multi-rotor, and hence you might not get a chance to put it into a hover. In most cases, a launcher is needed to get a fixed-wing drone into the air.

•With fixed-wing, the flight is just the beginning. The hundreds and thousands of captured images have to be processed and stitched together into one big tiled image. There is a lot more to be done after this, including performing data analysis, such as the stockpile volume calculations, tree counts, overlaying other data onto the maps, and so on.

Technical Uses:

•Aerial Mapping

•Drone Surveying – Forestry/Environmental Drone Surveys, Pipeline UAV Surveys, UAV Coastal Surveys

•Agriculture , Inspection, Construction, Security

https://www.auav.com.au/articles/drone-types/#1

Analog Photogrammetry. Analog photogrammetry represents the first era (also called the classical era) of photogrammetry. Either full-scale or reduced-scale film *diapositives* (positive photographs on a dimensionally-stable transparent medium, film or glass, as opposed to a positive paper print which is not transparent) are used with analog plotters that physically replicate (at reduced scale) the spatial geometry that existed when a strip of overlapping stereo photographs was taken. Aerial triangulation is performed manually with analog plotters and requires a great deal of operator expertise.

Optical Stereo Plotters. Among direct optical systems, Zeiss Multiplex projectors (Figures 4-2 and 4-3) were widely used in the 1930s and 1940s to include World War The Multiplex used reduced-scale (2”x2”) *diapositives* produced from the original film negatives (9”x9”). Even- and odd-numbered projectors would project the images through red and blue filters into *image space*. By using anaglyph glasses (similar to those now used in 3D movies), the operator could see 3D *stereo models* in this *image space* by viewing only the red images with one eye and only the blue images with the other eye. To obtain *relative orientation*, the angular orientation of each projector would be adjusted to replicate the roll, pitch and yaw of each image when originally taken by the camera – an extremely labor-intensive task. Additional labor- intensive steps were taken to obtain *absolute orientation* to ground control. Furthermore, photo- identifiable features did not come into focus in the stereo model until the platen of the tracing table was at the correct elevation for each feature to be mapped. The platen would be moved up and down as necessary to accurately trace planimetric features on the map manuscript in their correct horizontal locations and to map contour lines with uniform elevations. Other optical plotters were popular in the 1950s, using full-scale 9”x9” diapositives. Although Multiplex plotters are no longer used, these images are still a good way to explain to students how photogrammetry works, whether using analog, analytical or digital procedures.

https://ez-pdh.com/aerial-photogrammetry-help/

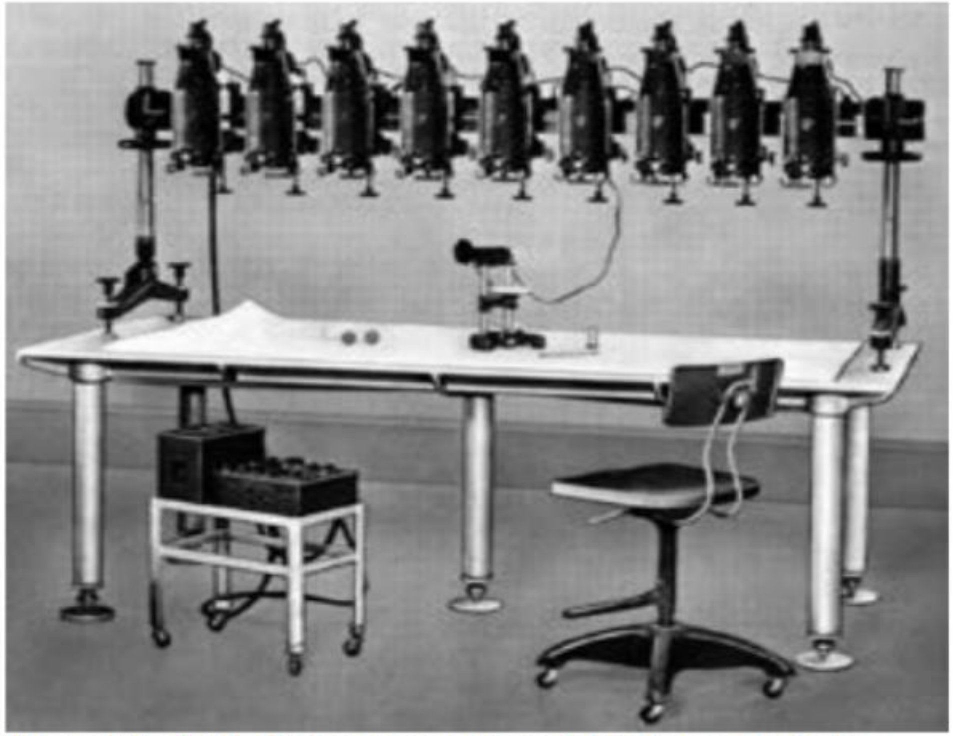


Figure 1-2. Multiplex projectors that physically replicate the geometry that existed when a flight line of nine aerial photos was taken. Without accurate *relative orientation*, the stereo images could never be focused in 3D in the stereo model, and without *absolute orientation*, the map would never fit ground control.

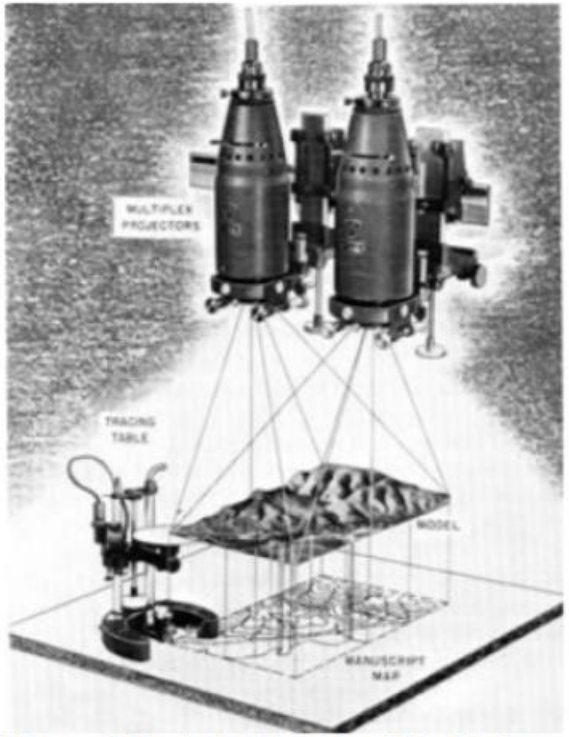


Figure 1-3. A single pair of Multiplex projectors, showing the stereo model, tracing table and map manuscript drawn with a pencil directly below a dot on the platen of the tracing table.

https://ez-pdh.com/aerial-photogrammetry-help/

Optical-Mechanical Stereo Plotters. Optical-mechanical stereo plotters were popular through the 1970s. They used metal space rods to simulate the direct optical projection of light rays. Wild A8 Autograph with coordinatograph that plots map manuscripts. Full-scale 9”x9” diapositives were carefully mounted in the stages shown at the top. Looking through eye pieces, operators could view the left image directly with the left eye and the right image with the right eye, without need for anaglyph glasses. One hand crank moved the space rods (as well as the coordinatograph) in the X-direction, causing a “floating dot” in the eyepiece to appear to move across the image in the direction of flight between the first and second photographs, and the second hand crank did the same in the Y-direction. The foot petal changed the elevation being viewed. When the “floating dot” appeared in focus on the ground (when viewed in stereo), the two space rods were effectively intersecting at the correct elevation. Contour lines of equal elevation were plotted by moving the two hand cranks to keep the floating dot on the ground while keeping the foot petal unchanged. With most optical-mechanical stereo plotters, the photogrammetric solution was achieved by means of physically altering the positions and rotations of the stages holding the film media relative to each other. Aerial triangulation (AT) processes were very complicated, normally establishing relative orientation only between two images at a time, then cantilevering independent stereo models until photo-identifiable control points enabled absolute orientation of the models. Early systems produced only hardcopy maps while the advent of computers enabled upgraded systems capable of digital data recording. Although more expensive than optical projectors, the optical- mechanical stereo plotters were preferred over direct optical systems because they were more versatile (with later versions modified with encoders for digital recording of coordinates), produced maps of higher accuracy, had better overall stability, and did not need to be operated in dark rooms. Very few optical-mechanical stereo plotters remain in use today in the U.S.

https://ez-pdh.com/aerial-photogrammetry-help/

Figure 1-4. Wild A8 Autograph with coordinatograph for plotting of map manuscripts from stereo photos. The A8 pictured here was upgraded with electronics for data entry and digital recording of data. The A8 was the photogrammetric "workhorse" for nearly three decades – one of many different models of optical-mechanical stereo plotters produced by Wild Heerbrugg, Zeiss, Kern and other photogrammetric equipment manufacturers during the analog era.

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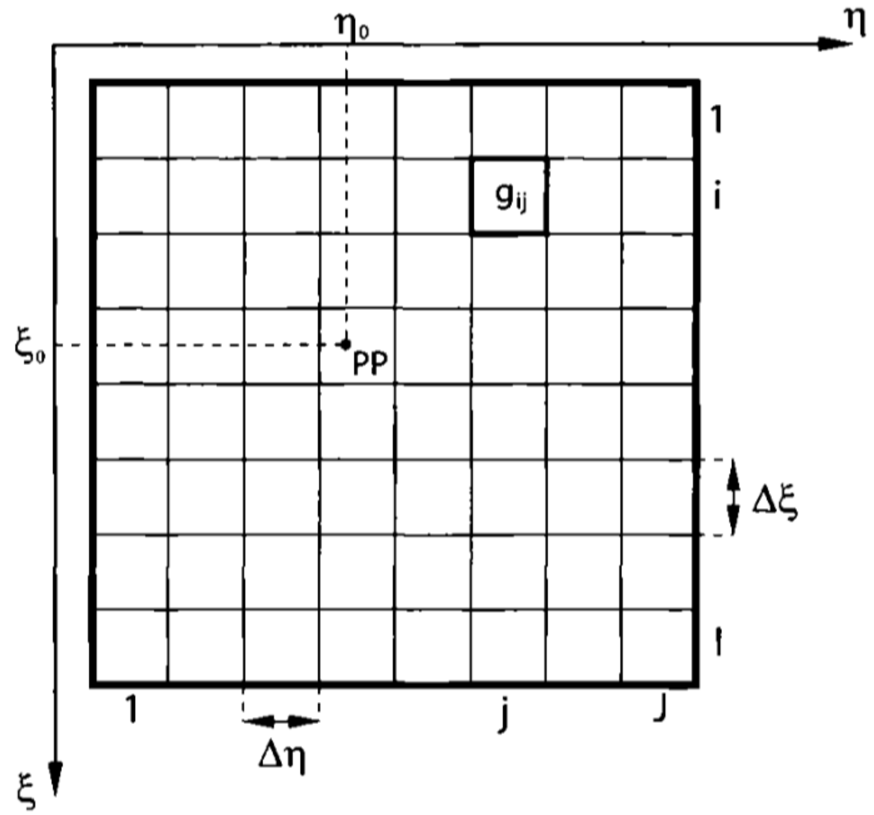
Analytical Photogrammetry. Analytical photogrammetry, which represents the analytical era of photogrammetry starting in the 1960s, also uses full-scale (9”x9”) film diapositives but *mathematically* replicates the spatial geometry that existed when strips of overlapping stereo photographs were taken. The analytical era included the development of advanced methods of treating quantitative observations of phenomena affecting the photogrammetric operation, to include atmospheric refraction, for example, where light rays may not be perfectly straight. The metal space rods and linear scales from optical-mechanical plotters were replaced with colinearity equations, computer models and microprocessors for analytical stereo plotters. Most significantly, microprocessors record the 2D photo-coordinates of *pass points* and *tie points* on stereo photographs, automate the AT solutions for large blocks of imagery, including multiple flight lines, and compute the 3D ground coordinates of the *pass points* (that link common points in the overlap areas of two or three images in the same flight line) and *tie points* (that link common points in the overlap areas of adjoining flight lines).

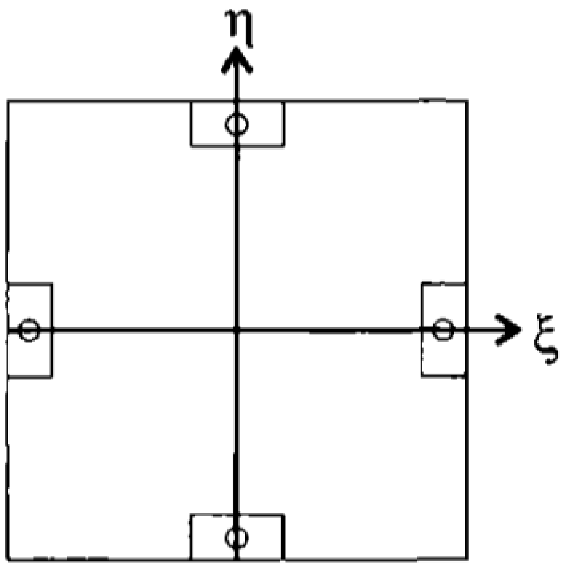
Figure 1-5. Wild BC2 analytical plotter that automates aerial triangulation and simplifies photogrammetric mapping processes. On the table to the right, a point marking and transfer device is shown that drills very small holes in the film emulsion for measurement of *pass points* and *tie points* used in aerial triangulation (AT).

Photogrammetry. Digital photogrammetry, also called *softcopy photogrammetry*, represents the third and current era of photogrammetry. This era started around 1990 with the introduction of digital stereo photogrammetric workstations and high resolution scanners that converted film into digital imagery. The subsequent introduction of modern digital metric cameras further established softcopy photogrammetry as the dominant technology as film photography became less and less viable, and as major film manufacturers halted production of film for aerial cameras. Charge Couple Devices (CCDs) used in digital cameras have a wider dynamic range, improving the accuracy and appearance of finished products, and digital imagery eliminates processing steps necessary with hardcopy photos. With digital photogrammetry, the costly optical-mechanical stereo plotters have been completely replaced by computers, monitors and software that apply complex photogrammetric concepts and sophisticated image-processing techniques, including automated image correlation that enables thousands of *tie points* and *pass points* to be automatically generated rather than manually generated as with analytical photogrammetry. Figure 4-7 shows a digital stereo photogrammetric workstation running software for photogrammetry and lidargrammetry, coupled with GIS software for real time display and analysis. If this looks similar to a typical desktop computer – that's because it is similar, and that's the main advantage, i.e., photogrammetric firms now use mass-produced computers with specialized photogrammetric software rather than purchasing expensive specialized hardware required during the analog and analytical eras. Simultaneous AT block adjustments are now performed with over 20,000 digital images per block of images and millions of auto-correlated *pass points* and *tie points*, rapidly and accurately providing the six exterior orientation parameters needed for each image (X/Y/Z coordinates of the lens focal point, and roll/pitch/yaw of the camera, when each image was taken). Automatic image correlation also enables the simplified generation of Digital Surface Models (DSMs) and the highly popular digital orthophotos produced by draping unrectified digital aerial imagery over a DSM or DEM. Digital photogrammetric software is also used in lidargrammetry discussed in Chapter 6 of this manual.

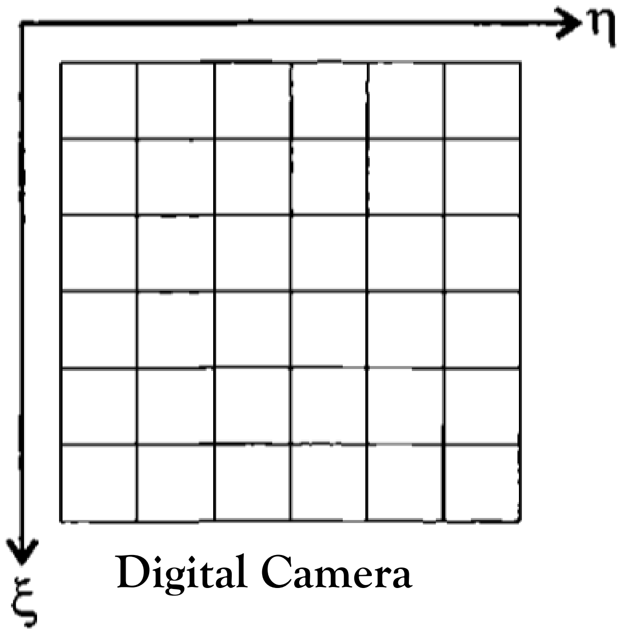
Digital Metric Picture

A digital metric image is a digital photograph which meets the requirements of photogrammetry. The basic prerequisites are that the image should have been formed by central projection and that the perspective centre should be fixed in relation to the image The digital metric image is formed in the image plane of a digital (metric) camera. The digital metric image consists of a (two-dimensional) matrix G with picture elements





Film Camera



Digital Camera

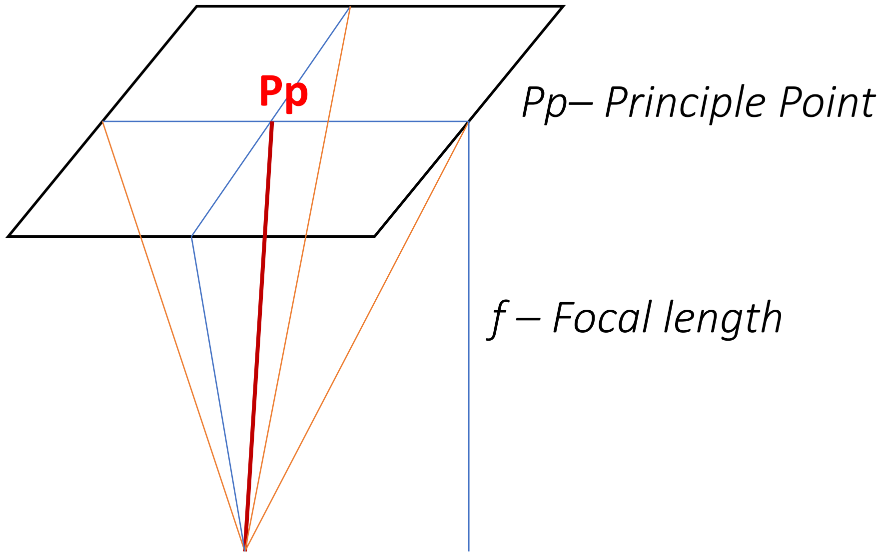
Image coordinate system in an analogue metric camera (film camera, left) and a digital metric camera (digital camera, right)

Geometric aspects of CCD cameras

When CCD cameras are employed for photogrammetric purposes it is, as a rule, necessary to have knowledge of the interior orientation. The required parameters are defined in the calibration certificate and are:

- the principal distance
- the coordinates of the principal point of autocollimation and principal point of best symmetry
- the objective lens distortion.

In addition, CCD cameras must also provide information on the positions of the active detector elements and the planarity of the recording surface defined by the surfaces of the detectors.



Radiometric aspects of CCD cameras

The electrical signals delivered by CCD sensors are largely proportional to the number of photons incident on the detectors. Departures from linearity can be held to within 1 % of the true value34 but there are very large departures from linearity when the semi- conductor elements are close to saturation. In fact, very large amounts of radiation cause an "overflow" into the neighboring detector elements. The result is blooming, similar to the effect which also occurs with very bright objects imaged onto film. The spectral sensitivity of the silicon sensors normally used ranges from 400 to around 1100 nm,

The radiometric resolution of **14 bits enables** the capture of quality images, even in poor light conditions. Image size is **6,096 x 6,500 pixels** and the multispectral sensor allows simultaneous capture of true-colour (RGB) and NIR images. The RMK D evolved from Intergraph's Digital Mapping Camera (DMC), a large-format digital camera introduced in early 2003

The Vexcel UltraCamL, panchromatic array size **9,735 x 6,588** (**colour and NIR: 5,320 x 3,600**), is also a **medium-format** camera, while its successor, the UltraCamLp, is **large-medium format**, array size **11,704 x 7,920** and **4.3cm GSD** at 500m flying height**.** With an image format of 196 mega pixels (17,310 across track x 11,310 along track) and pixel size of **six micrometre**, Vexcel's UltraCamXp is a high-end large-format digital frame camera. Vexcel Imaging introduced the UltraCamX in 2006, preceded by the UltraCamD in 2003. Today the large-format models are the UltraCamXp (2.9cm GSD at 500m flying height) and UltraCamXp Wide-Angle (4.3cm GSD at 500m flying height)

https://www.gim-international.com/content/article/digital-aerial-cameras-2

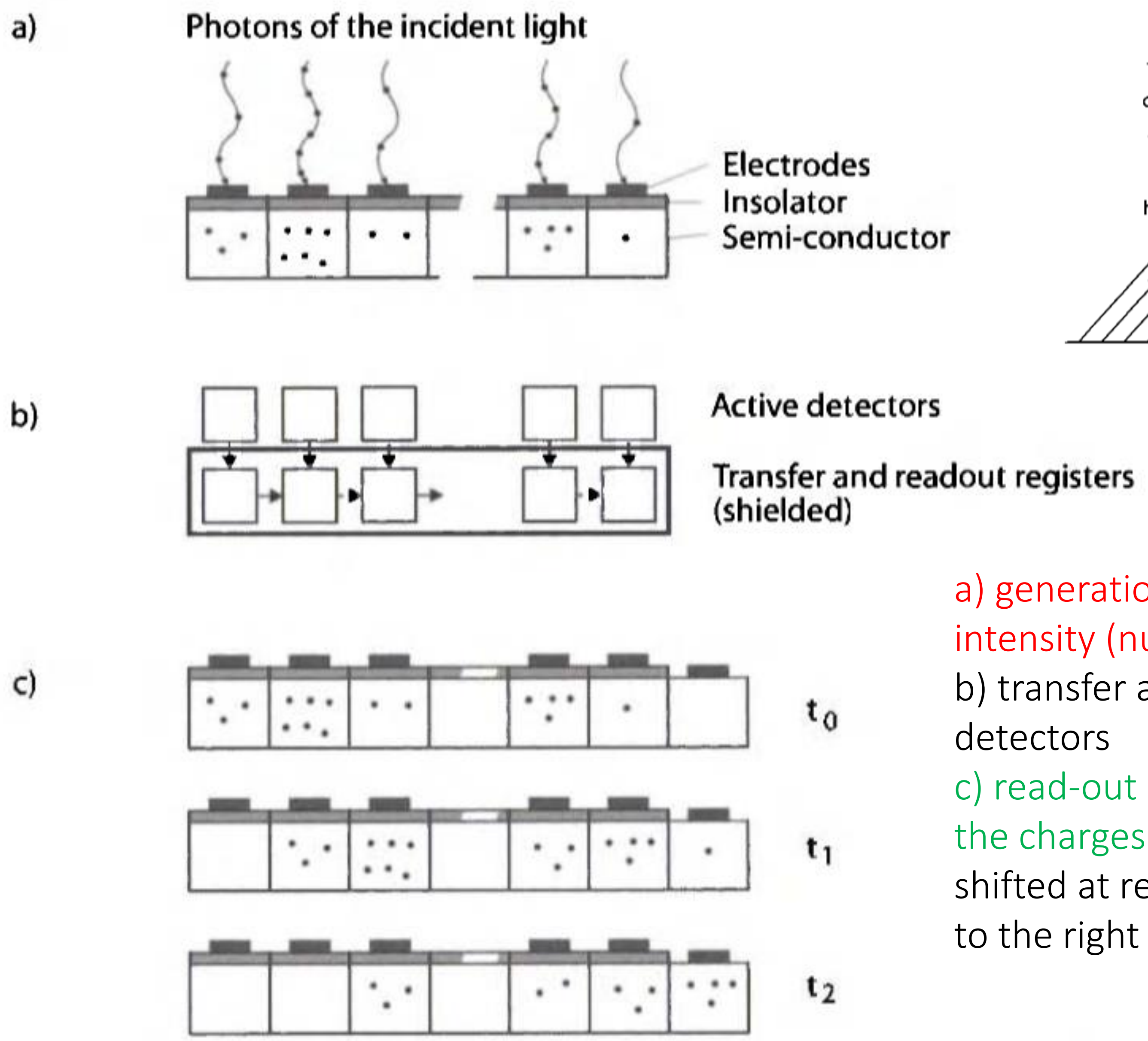
Photoelectronic Image Recording

Sensor in the image plane of a metric camera. Instead, an electronic sensor which directly supplies a digital image is becoming more common.

The principle of opto-electronic sensors is presented.
These devices are suitable for digitally recording optical radiation - electromagnetic spectrum covering **visible** and **infra-red light**

Digital Sensors

Solid state sensors are exclusively used nowadays for digital image recording in photogrammetric cameras.
They consist of a large number of detectors which register the photons of the incident light falling on the image plane of the camera. The principle of opto-electronic image recording by means of semi-conducting elements (preferentially made of silicon) for a linear array sensor.
In the semi-conducting elements under the electrodes, the photons of the incident light build up an electrical charge by creating electron-hole pairs. This charge is proportional to the number of incident photons (the photo-electric effect).



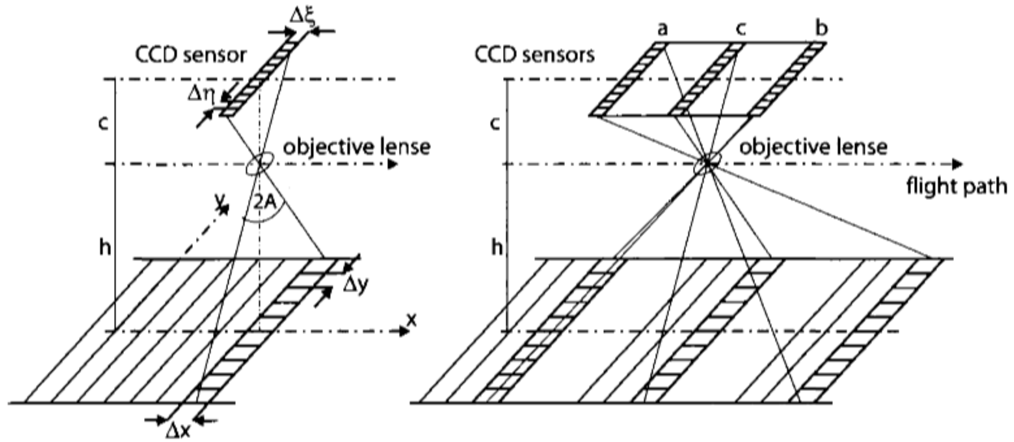


Figure 3.3-3: Line camera (left) and 3-line camera (right)

a) generation of charge in semi-conductor according to the intensity (number of photons) of the incident light.

b) transfer and read-out registers arranged next to the active detectors

c) read-out principle by means of CCD (charge coupled device): the charges are

shifted at regular time intervals (to, t1, t 2 , . . .) by one element to the right and quantized when they reach the last element

Resolution and Modulation Transfer

The recording quality of opto-electronic image sensors, in terms of their resolution and contrast transfer, is primarily influenced by the size of the pixels $A\xi \ \chi \ A\eta$. The size of the pixel at the object is given by projecting the surface of an individual detector element through the camera optics onto the surface of the object, for example the Earth's surface. For vertical images taken of flat ground, the size of a pixel $A\chi \ \chi$ Ay on the ground surface, commonly referred to as "the **footprint**"

Digitizing analogue images

The explanations above have shown that the geometric resolution of analogue photography is significantly higher than the geometric resolution of current opto-electronic (area array) sensors. For many years to come, therefore, objects will be recorded by light-sensitive film in metric cameras when executing the most accurate photogrammetric tasks. However, in order to apply the methods of digital photogrammetric analysis, film can be digitized after development

Sampling interval

The sampling interval, which equates to the distance between each pixel in an orthogonal grid, must be compatible with the resolution in the analogue image in order to avoid loss of information. Section 3.2.2.7 discussed the geometric resolution RT of a "photographic emulsion" sensor. For current films it varies between 50 and 100Lp/mm. In a similar way to the sampling theorem, the digitization sampling intervals X & Y in both coordinate directions should be chosen as follows

$$\Delta\xi_s\,[\mathrm{mm}] = \Delta\eta_s\,[\mathrm{mm}] = 0.7/(2R)$$

Numerical Example. Adequate sampling intervals for the analogue images mentioned above are between 3.5 and 7 μm (e.g.: $\Delta\xi_s = \Delta\eta_s = 0.7/(2 \times 50) = 0.007\,\mathrm{mm} = 7\,\mu\mathrm{m}$).

At a sampling interval of 7 /μm, a 23 cm χ 23 cm metric image requires a storage capacity of approximately 1 gigabyte, where 1 GB « $(230000/7)^2$.For a colour image it would be 3 GB

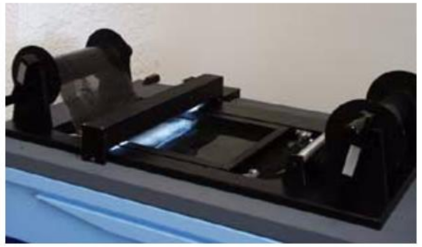
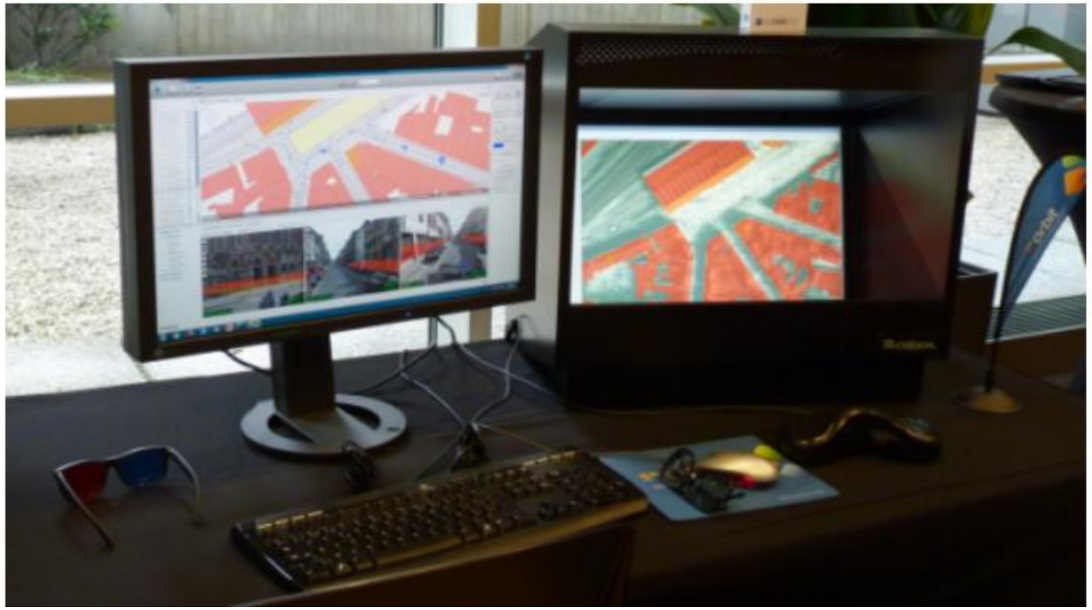


Image Source: ETH Zurich Research Collection

UltraScan 5000

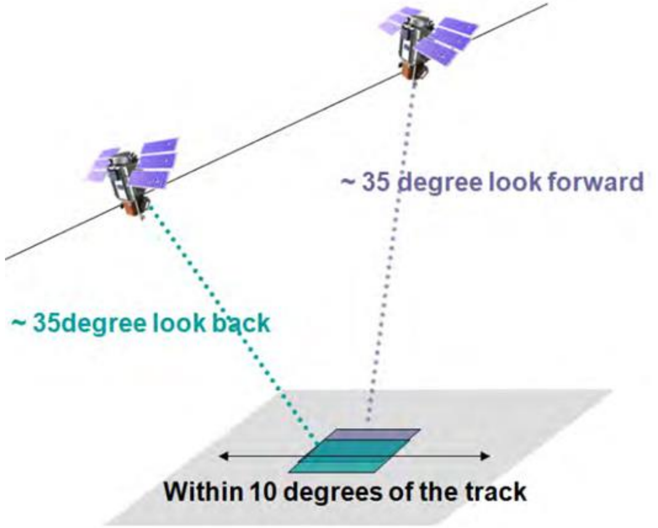


https://kb.orbitgt.com/112/photogrammetry/strabo/introduction/hardware

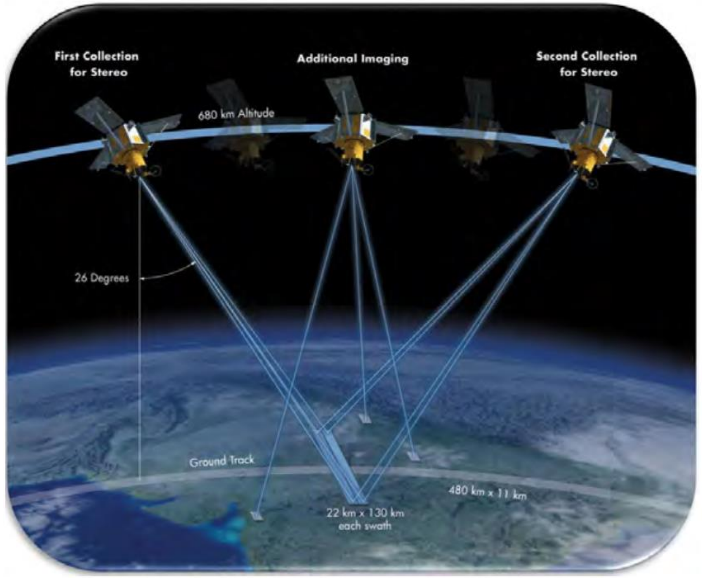
3D Stereo visualization with 3D PluraView

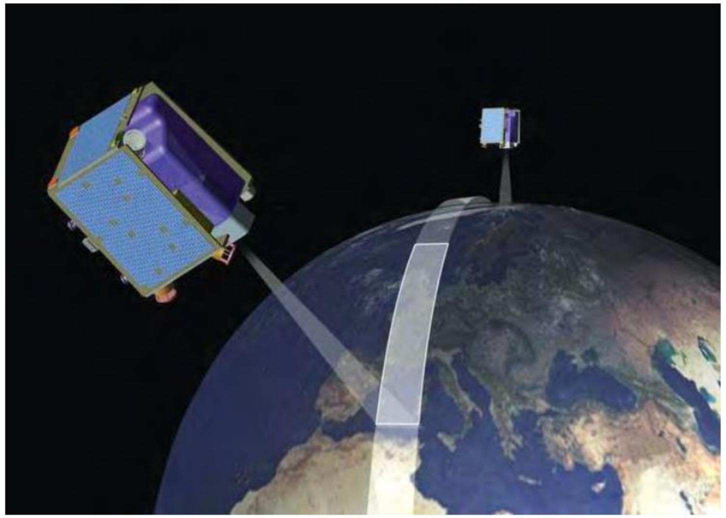
Satellite Imagery Stereo

Creating Satellite Imagery Stereo Pairs. Most high resolution imaging satellites are push broom sensors that not only can look forward, downward or backward, but can also roll to the left or right to capture target areas of interest (AOIs), adding to the complexity of the stereo model acquisition geometry. Images in this section were provided as a courtesy by Digital Globe. Fore/aft stereo imagery derived from the same pass (in track) over a target with camera looking forward in the first collect (fore) and backward in the second collect (aft).



Collecting an image at nadir, i.e., looking straight down at the target, doesn't happen with high-resolution satellite imagery; satellite sensors always shoot at an angle. This agility improves imaging revisit times and, with some satellites, enables stereo collects for 3-D elevation modelling

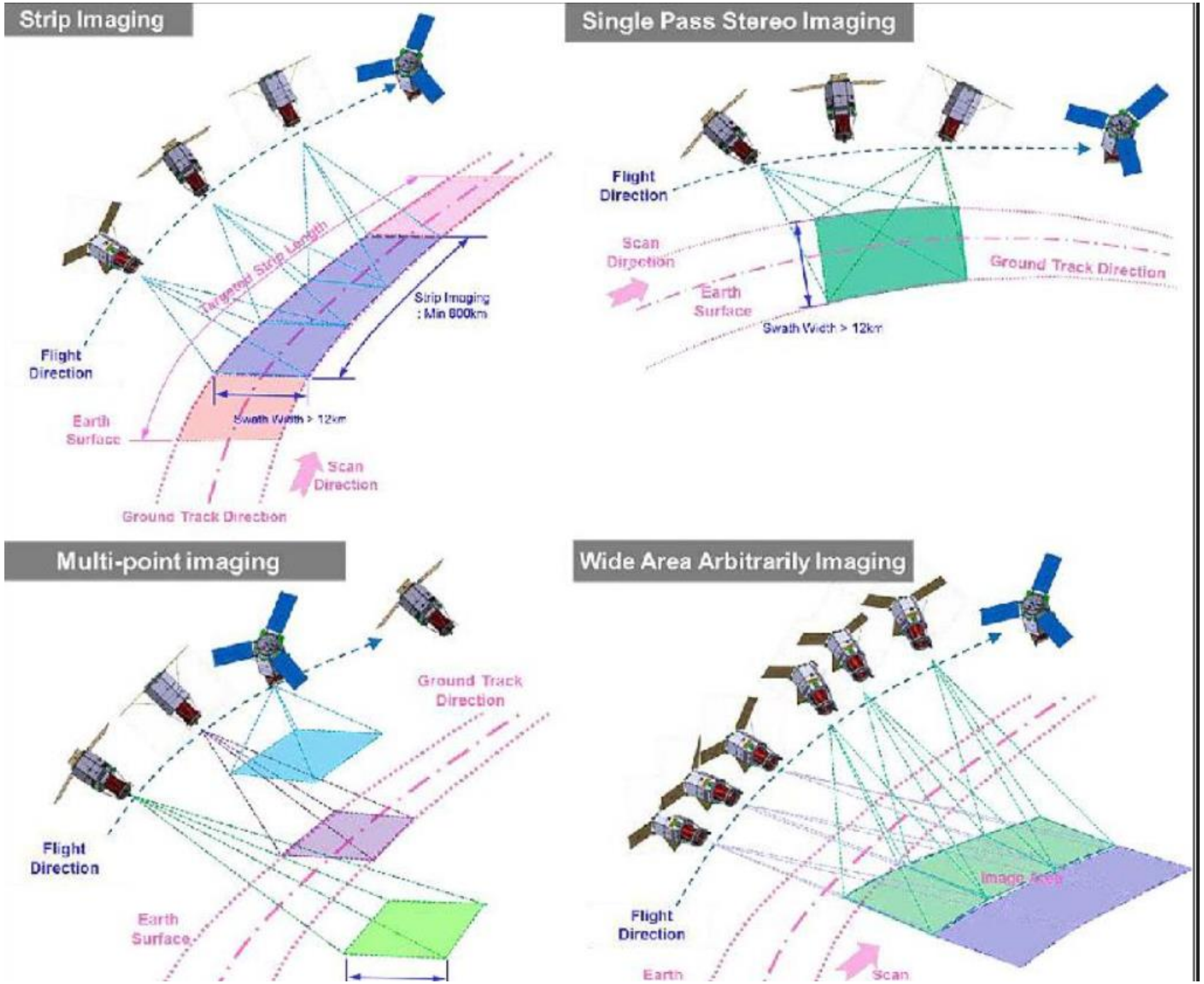




RapidEye's constellation approach permits a cumulative swath to be built up as multiple satellites view adjacent regions of the ground

Satellite agility enables the satellite to point in different directions and collect imagery off-nadir.

https://cdn.ez-pdh.com/course-material/LS1007-Satellite-Photogrammetry.pdf



KOMPSAT-3A Imaging Modes

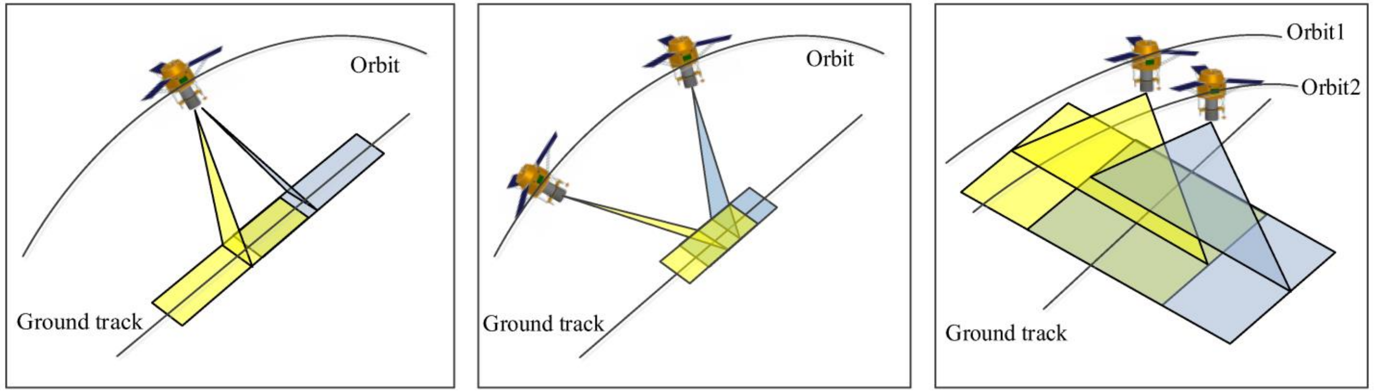
•**Strip imaging** is a scanning method in which the scan direction is aligned with satellite velocity. The satellite is fixed in LVLH coordinate and the yaw steering manoeuvre is automatically performed to eliminate the effect of the earth's rotation.

•**Single-pass stereo imaging** is a scanning method in which the scan direction is the same as strip imaging, but the satellite takes two images of the same target in the same pass. The first image is taken at a positive pitch tilt angle, and the second image is taken at a negative tilt angle. Therefore the two images of different viewpoints can be utilized to generate 3D images.

•**Multi-point imaging** is a scanning method in which the satellite takes an image and quickly rotates the body to the next position to take several images in a different location. While scanning, the satellite body is fixed in the LVLH coordinate.

•**Wide arbitrary imaging** is a scanning method in which the scan direction is different from the satellite velocity. Therefore, the ground track can be in an arbitrary direction such as a direct north direction, east direction, or west direction.

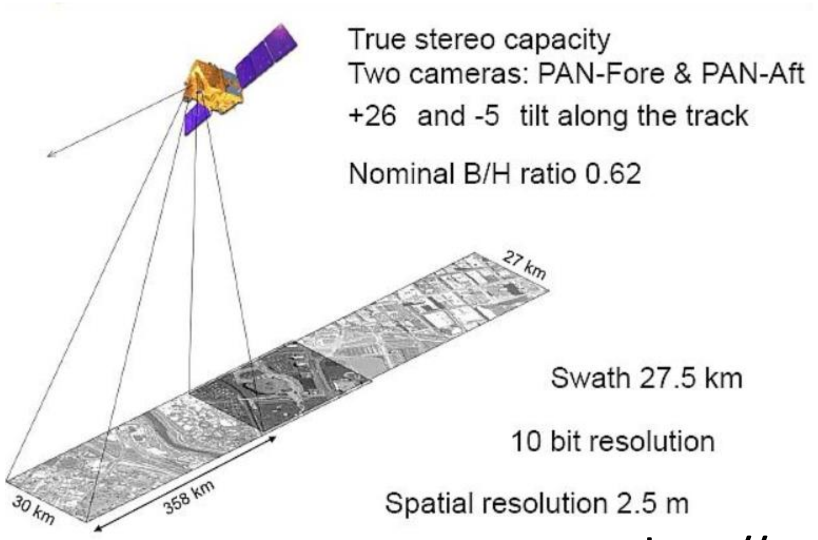
https://www.eoportal.org/satellite-missions/kompsat-3a#kompsat-3a-imaging-modes

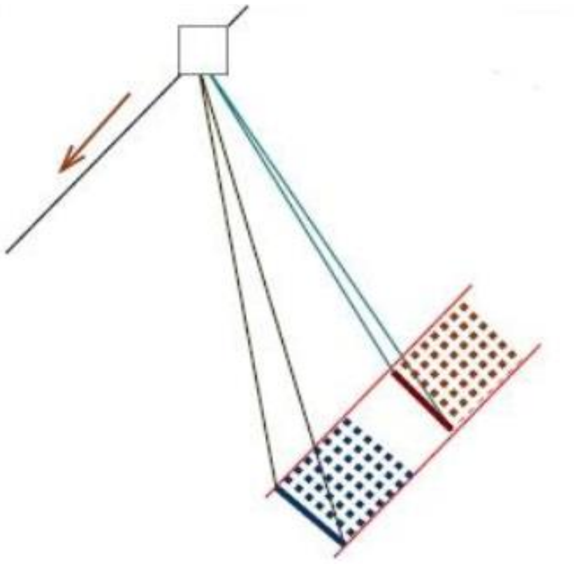


(**a**) Multiline Stereo Mode (**b**) Agile Stereo Mode (**c**) Wide Swath Stereo Mode

Three different stereo mapping mode. (**a**) Multiline array cameras attain multiple images at different angles, baselines, and overlapping areas, (**b**) one camera observes the same area from different angles at the same orbit by the attitude maneuver, (**c**) one camera observes the same area from different orbits without requiring attitude agility

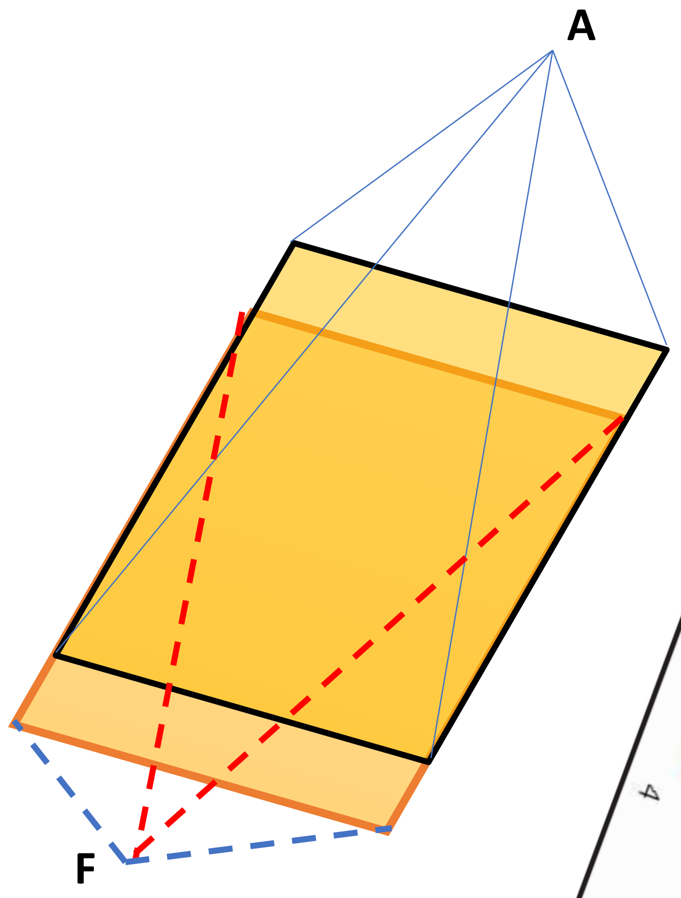
https://www.mdpi.com/1424-8220/18/3/739

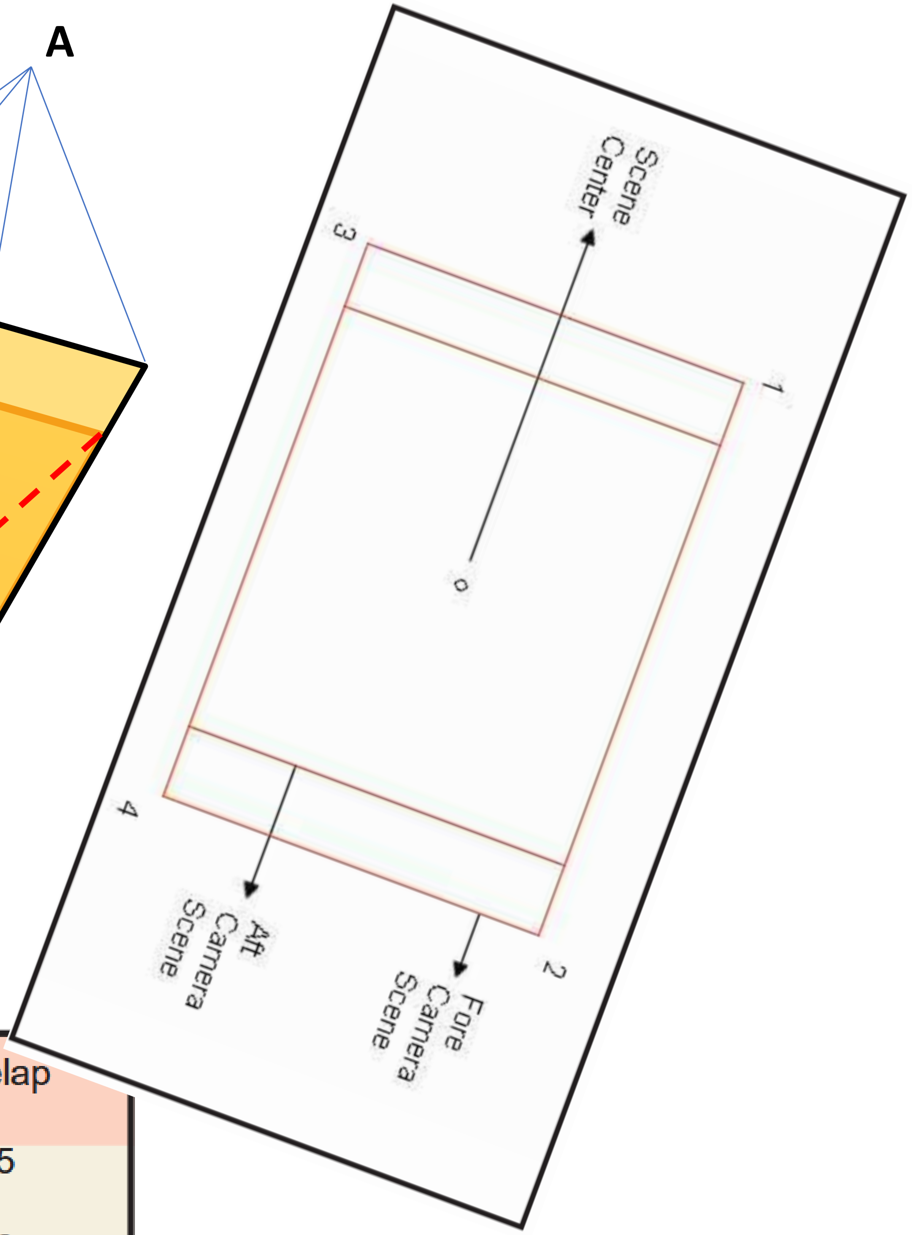




https://www.eoportal.org/satellite-missions/irs-p5#pan

CARTOSAT





Orbits/cycle	1867
Repeat cycle	126 days
Altitude	618 km
Semi-major axis	6996.132 km
Inclination	97.87 deg
Eccentricity	0.001
Period	97.18 minutes
Distance between adjacent traces	21.46 km
Distance between successive ground tracks	2704.6 km
Ground track velocity	6.94 km/sec

Payload (km)	Resolution (m) (m)	Swath (km)	Ground Image size (km X km)	Overlap (km)	Sidelap
Fore Camera	2.452	30	26.8 x 30	1.3	8.5
Aft Camera	2.187	26.8	26.8 x 26.8	1.3	5.3

Satellite System	Vendor	Spatial Resolution (meters)	Wavelengths (nanometers)	Radiometric Resolution	Temporal Resolution (days)
Ikonos 9/24/1999	DigitalGlobe	Panchromatic: 0.83 Multispectral: 4	Pan: 526-929 Blue: 445-516 Green: 506-595 Red: 632-698 NIR: 757-853	11-bit	2.9 days at 1m 1.5 days at 1.5m
QuickBird 10/18/2001	DigitalGlobe	At altitude 450 km Panchromatic: 0.61 Multispectral: 2.44	Pan: 405-1053 Blue: 430-545 Green: 466-620 Red: 590-710 NIR: 715-918	11-bit	2.5 days 5.6 days at 20º off-nadir or less
SPOT-5 5/3/2002	Astrium	Panchromatic: 2.5 and 5 Multispectral: 10	Pan: 480-710 Green: 500-590 Red: 480-710 NIR: 780-890 SWIR: 1,580-1,750	8-bit	2-3 days
WorldView-1 9/18/2007	DigitalGlobe	Panchromatic: 0.5	Pan: 400-900	11-bit	1.7 days at ≤1m 5.4 days at 20º
RapidEye 9/29/2008	BlackBridge	No Panchromatic Multispectral: 5	Blue: 440-510 Green: 520-590 Red: 630-685 Red Edge: 690-730 NIR: 760-850	12-bit	1 – 5.5 days

Satellite System	Vendor	Spatial Resolution (meters)	Wavelengths (nanometers)	Radiometric Resolution	Temporal Resolution (days)
GeoEye-1 9/26/2008	DigitalGlobe	Panchromatic: 0.41 Multispectral: 1.65	Pan: 450-800 Blue: 450-510 Green: 510-580 Red: 655-690 NIR: 780-920	11-bit	< 3 days
WorldView-2 10/8/2009	DigitalGlobe	Panchromatic: 0.5 Multispectral: 2	Pan: 450-800 Multispectral: Coastal: 400-450 Blue: 450-510 Green: 510-580 Yellow: 585-625 Red: 630-690 Red Edge: 705-745 NIR1: 770-895 NIR2: 860-1,040	11-bit	1.1 days at ≤1m 3.7 days at 20° off-nadir or less
Pléiades-1A 12/16/2011 Pléiades-1B 12/12/2012	Astrium	Panchromatic: 0.5 Multispectral: 2	Pan: 470-830 Blue: 430-550 Green: 500-620 Red 590-710 NIR: 740-940	12-bit	1 day with two satellites

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2. Wilfried Linder (2003) Digital Photogrammetry: Theory and Applications, Springer – Verlag, Berlin Heidelberg.
3. Wolf. P.R., (1974). Elements of Photogrammetry, McGraw Hill books Co., London.

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Thank You