Educational for Drone (eDrone)
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Educational for Drone
(eDrone)
Sensors for mission

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Università degli Studi del Sannio

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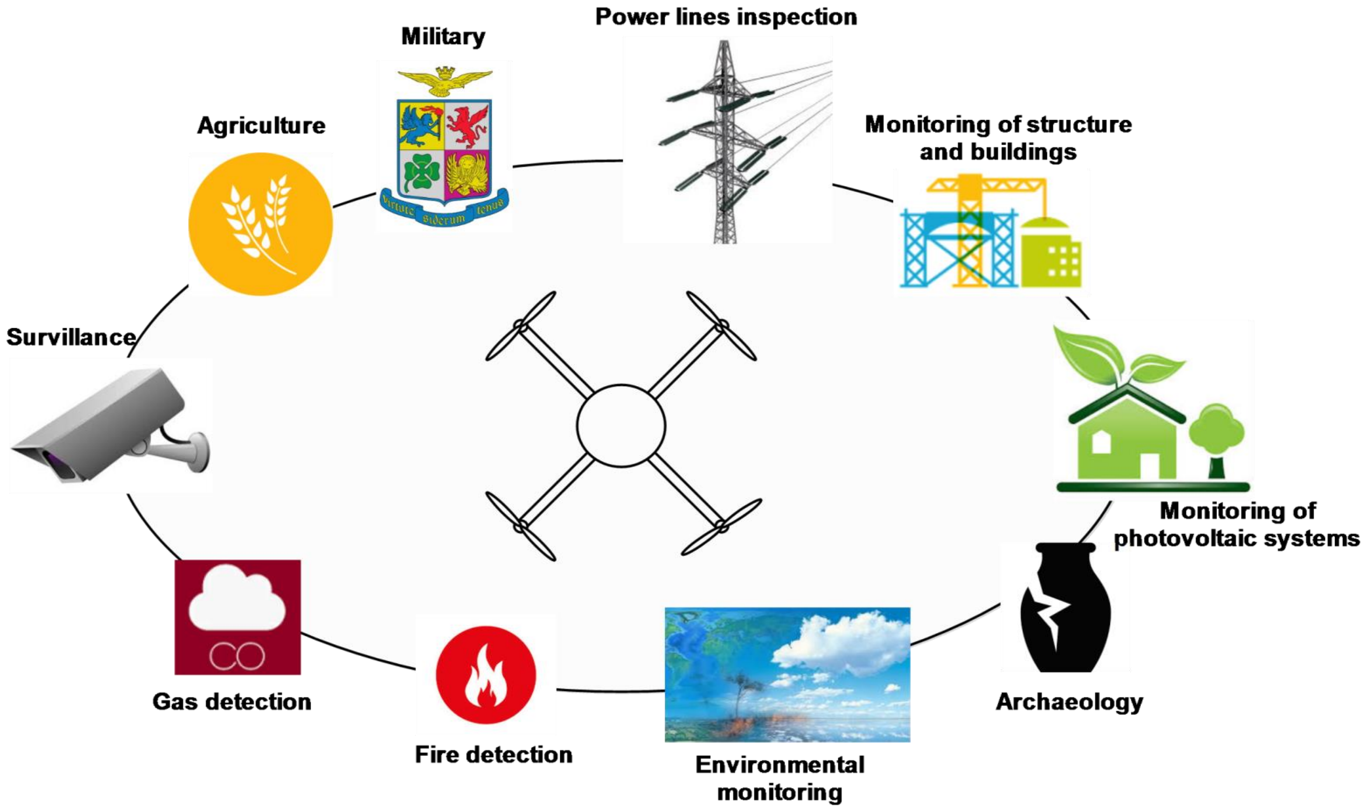
Monitoring applications with drones



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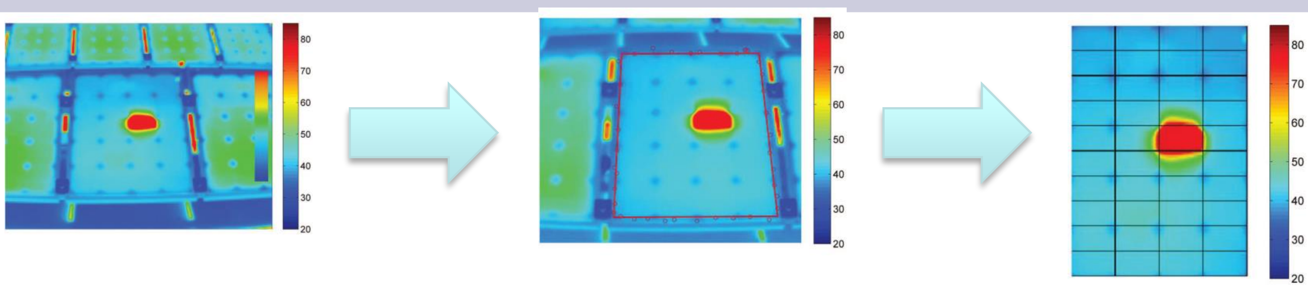
Monitoring of photovoltaic systems (1)

- The drone is equipped with:
  - Video camera, for detecting cracks, yellowing, snail trails and brunt cells;
  - Thermal camera, for detecting high temperature regions on a photovoltaic module surface (hot-spot);
  - GPS receiver for measuring the position related to an identified failure.
- The monitoring can be performed without power interruption.

Monitoring of photovoltaic systems (2)

Evaluation of temperature map for each acquired image → Panel edge identification and GPS localization → Prospective error compensation → Thermal analysis (in normal operations the temperature distribution is uniform)

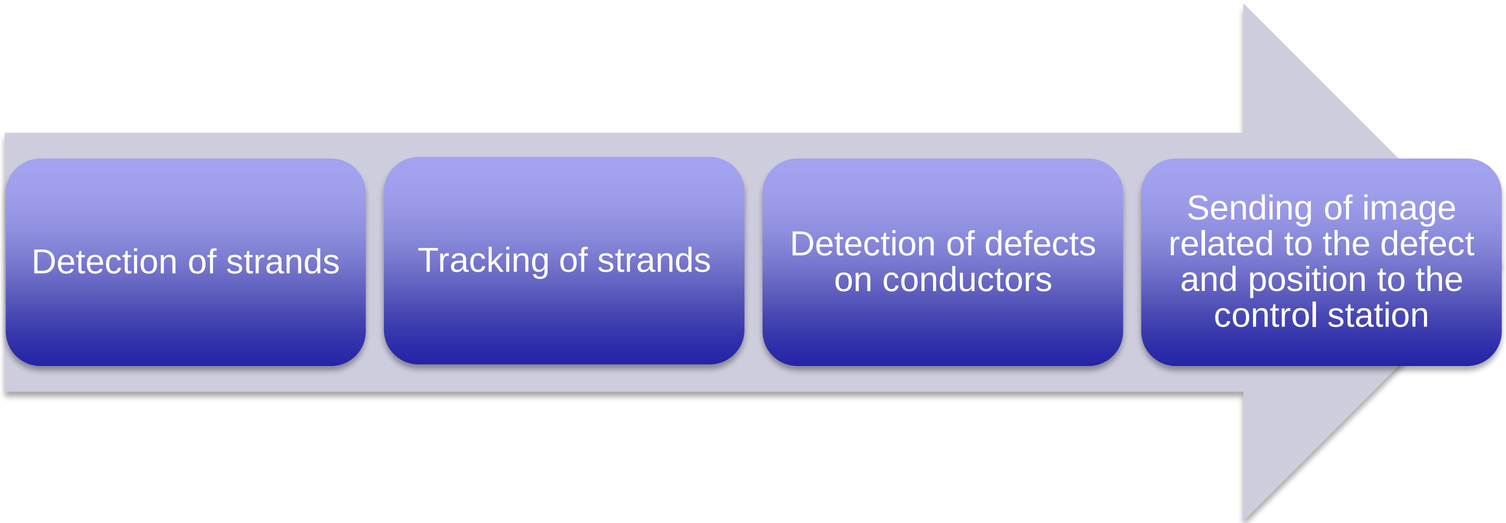


- The flight altitude affects the thermal image resolution;
- The drone shadow can affect the normal operation of photovoltaic panel;
- The position accuracy have to be high enough to localize a single panel;
- The detection is performed with post-processing methods.

Power line inspection (1)

- The drone is equipped with:
  - Video camera, for detecting broken strand;
  - Infrared camera, for preventing breakage of the strands;
  - Ultra-violet camera, for detecting corona effects
  - GPS receiver for measuring the position related to an identified failure.
- The power inspection with drone allow faster inspection than foot patrol and have the same or better accuracy than costly helicopter inspections.

Power line inspection (2)

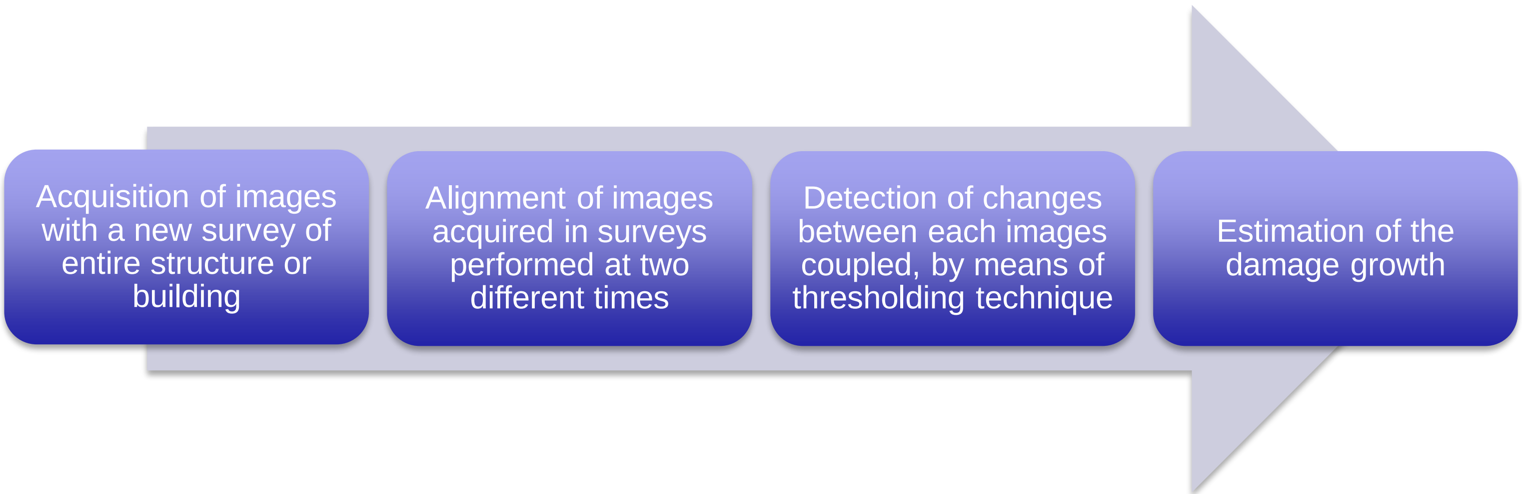


- High stability and high disturbances rejection during the flight;
- The environmental luminosity can affect the detection of defects with video camera;
- The position accuracy have to be high enough to localize a single defect;
- The detection is performed with post-processing methods.

Structural health monitoring (1)

- The drone is equipped with:
  - video camera;
  - GPS receiver.
- The industrial plants are made up of iron that usually deteriorates with time due to atmospheric factors, potentially causing very dangerous damage.
- Drone can be used for automatic monitoring and localization of damages.

Structural health monitoring (2)



- The luminosity changes can affect the performance of thresholding technique;
- The minimum size of the damage that can be detected depends on the flight altitude;
- The position accuracy has to be high enough to localize a single damage;
- The detection is performed with post-processing methods.

Environmental monitoring (1)

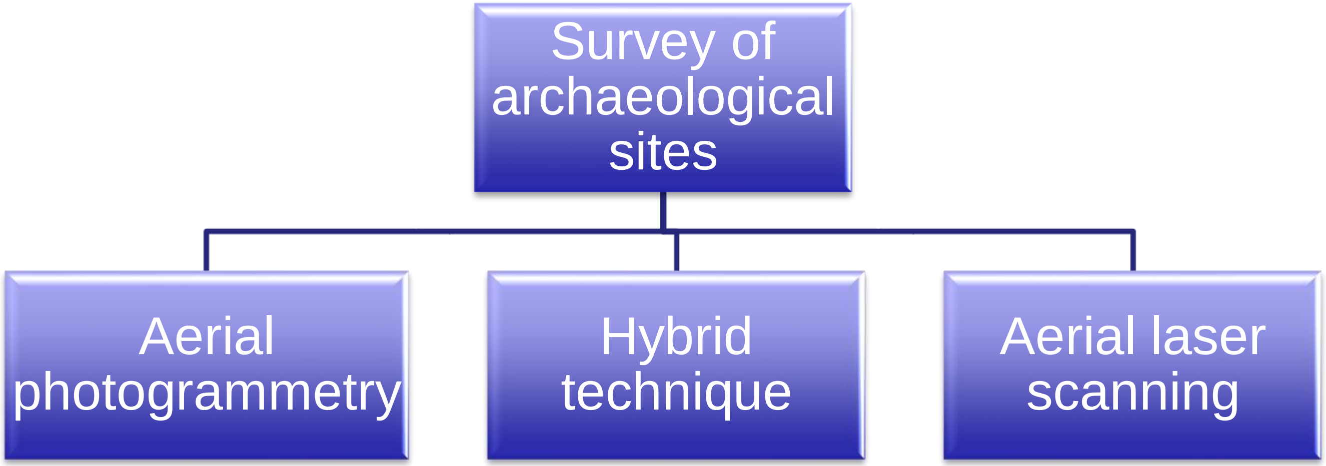
- The drone for environmental monitoring allow high spatial density measurements of several environmental quantities (e.g. relative humidity, gas concentrations, temperature).
- The drone equipment consists of GPS receiver and of a sensor board, which depend on the environment to monitor.
- The drone for water pollution monitoring (sediment pollution, oil spill, red tide, and thermal pollution):
  - Video camera;
  - Multi-spectral camera.
- The drone for marine low altitude monitoring:
  - Barometric pressure and humidity sensors;
  - High-definition camera.

Environmental monitoring (2)

- The drone for monitoring vegetation and soil:
  - Multi-spectral camera, for monitoring the state of vegetation (green leaves strongly absorb visible light and reflect near-infrared light).
- The drone for monitoring volcanoes activities:
  - Thermal camera for monitoring the temperature on the volcanic soil.
- According to the monitoring system, the parameters of a flight mission can affect the measurement accuracy (e.g. the temperature and humidity measurements are affected by drone movements, the accuracy of multi-spectral camera and video camera depend on flight altitude).
- All the methods require post-processing.

Documentation of archaeological sites

- Survey of archaeological site aims to obtain accurate measurements for producing maps and 3D models.
- An important task is to choose the appropriate technique for the specific survey.

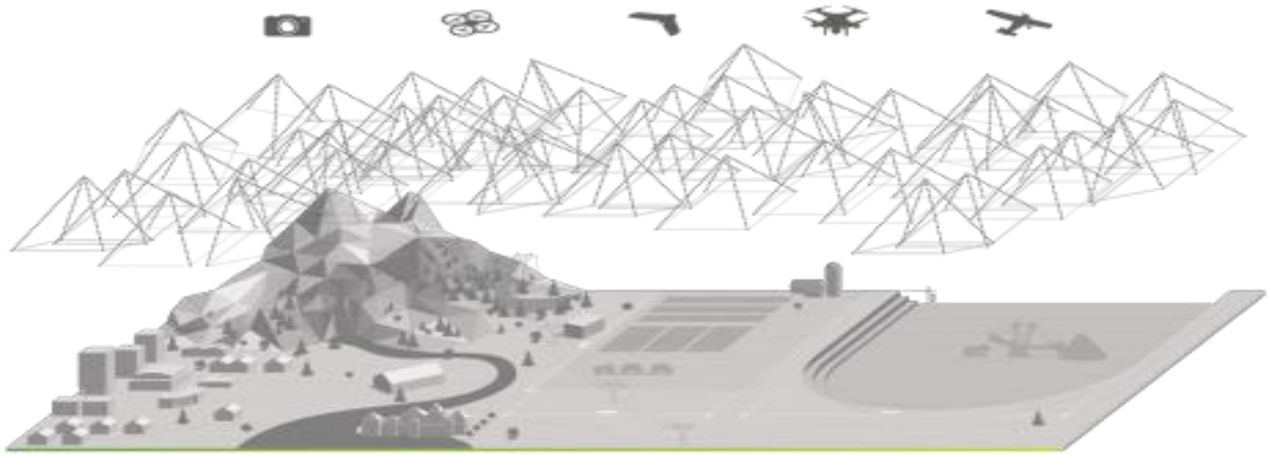


Aerial laser scanning

An ALS system consists of a drone with embedded a light detection and ranging (LiDAR) system.

Aerial photogrammetry

- This technique is used for the monitoring of wide sites or sites with difficult access.
- In aerial photogrammetry the 3D reconstruction is implemented by means of stereoscopic technique.
- The stereoscopic technique consists of observing objects from different positions.
- In aerial photogrammetry, the stereoscopic view is implemented acquiring two consecutive images during the flight mission.

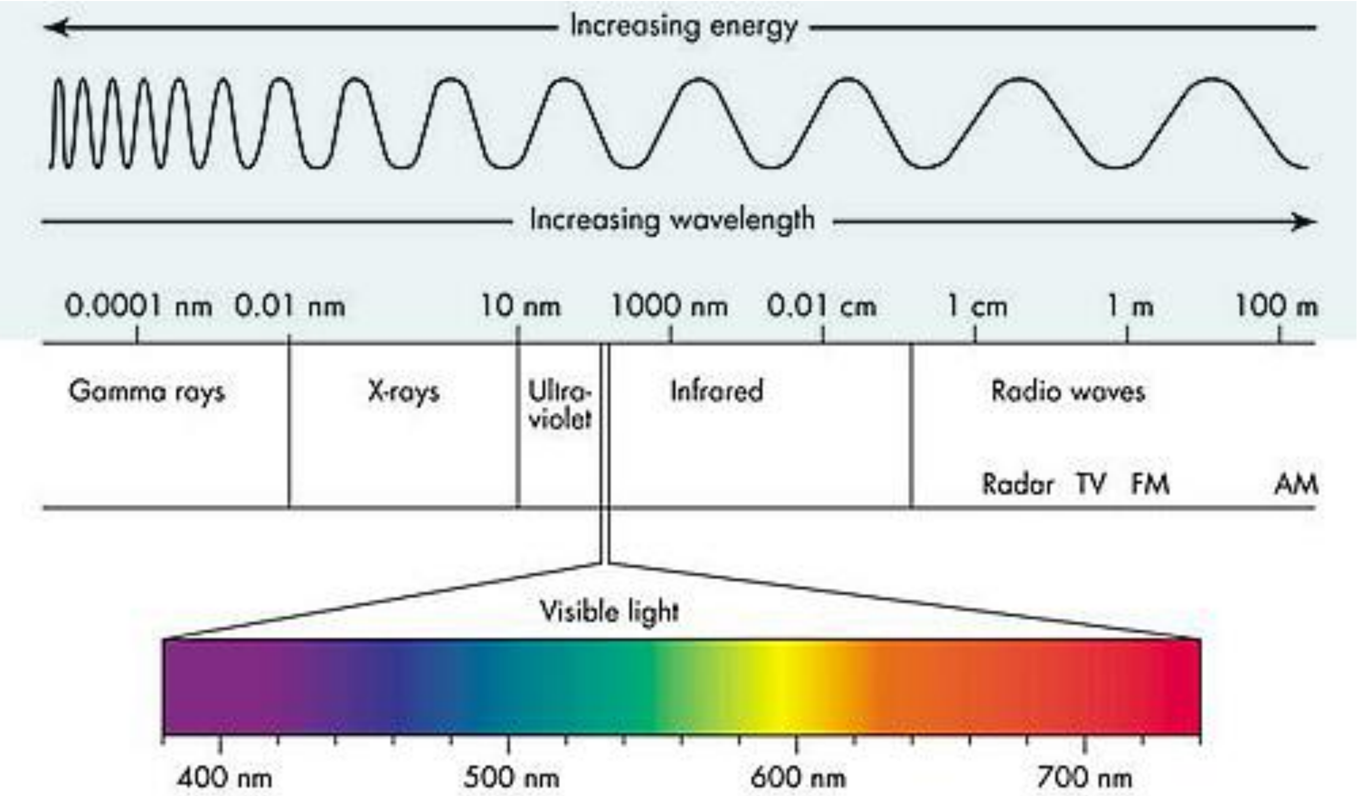


Sensors for mission

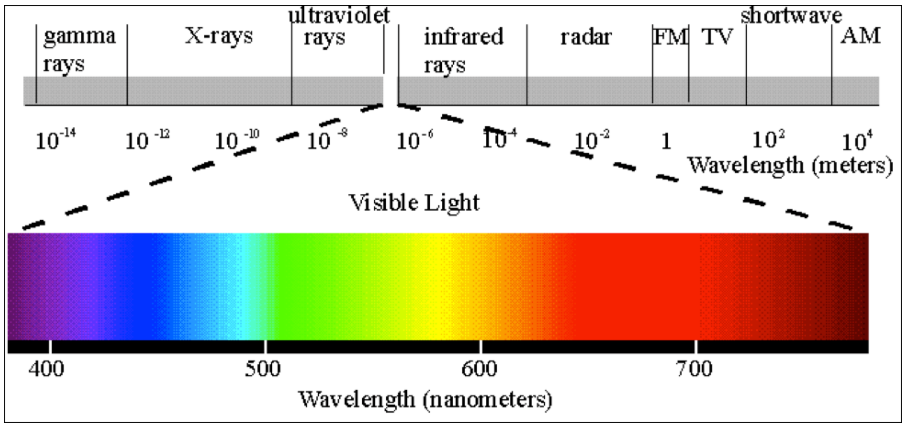
- RGB camera;
- Infrared camera;
- Multispectral camera;
- Light Detection And Ranging.




Light basics



Light basics



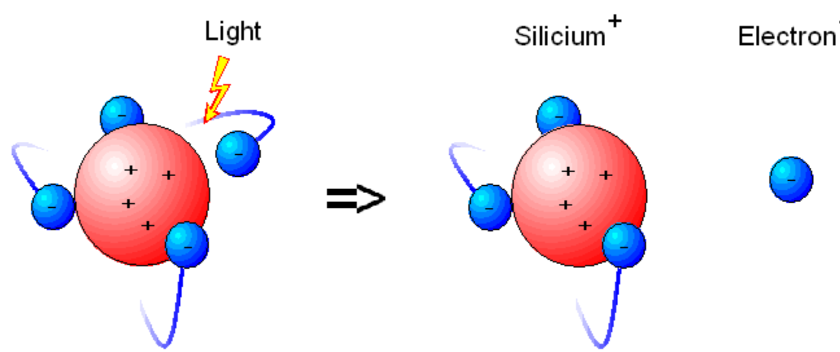
Visible light: 400 nm – 750 nm;

NUV: 200 nm – 400 nm;

NIR: 750 nm – 1100 nm.

$$E = \frac{hc}{\lambda}$$

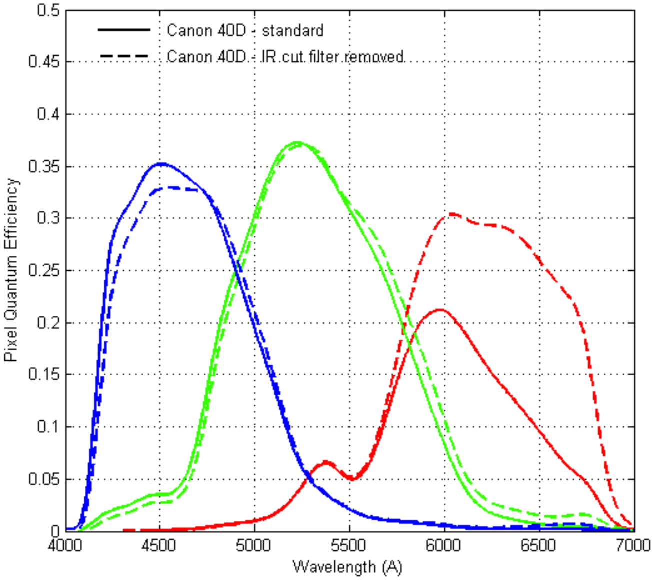
E = energy of photon;
h = Planck's constant;
c = Speed of light;
λ = wavelength of light.



Light basics

The Quantum Efficiency (QE) is defined as the number of electrons out per incident photon. QE is generally reported as a function of wavelength.

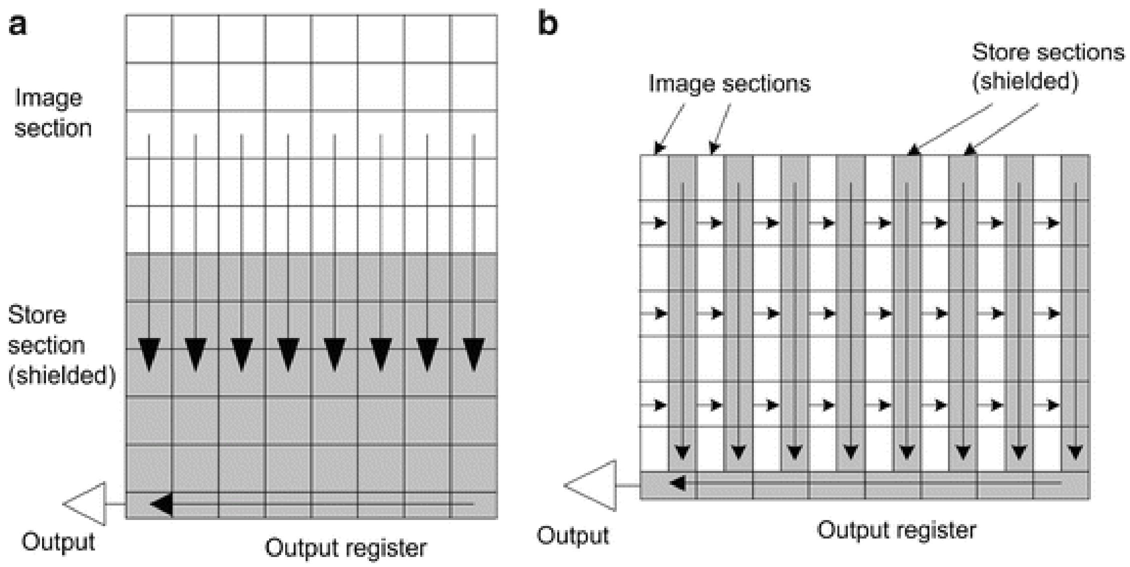
The Full Well Capacity is the maximum number of electrons that register a signal in a pixel. Larger pixels have higher well capacity which also leads to higher sensitivity, better Signal to Noise Ratio (SNR), and increased dynamic range.



4,000 electrons – Small pixels
10,000 electrons – Medium pixels
50,000 electrons – Large pixels

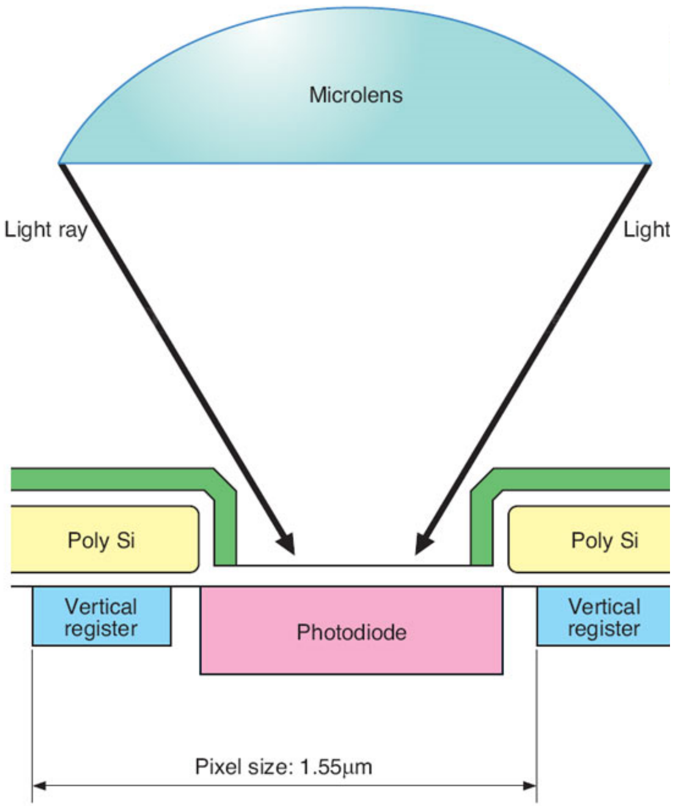
CCD sensors

- CCD Charge-Coupled Device are current driven devices;
- Charge is collected in pixels;



- The CCD output is an analog pulse where the charge is proportional to the light intensity.
- The charge is then physically shifted on the imager surface to the output for sampling.

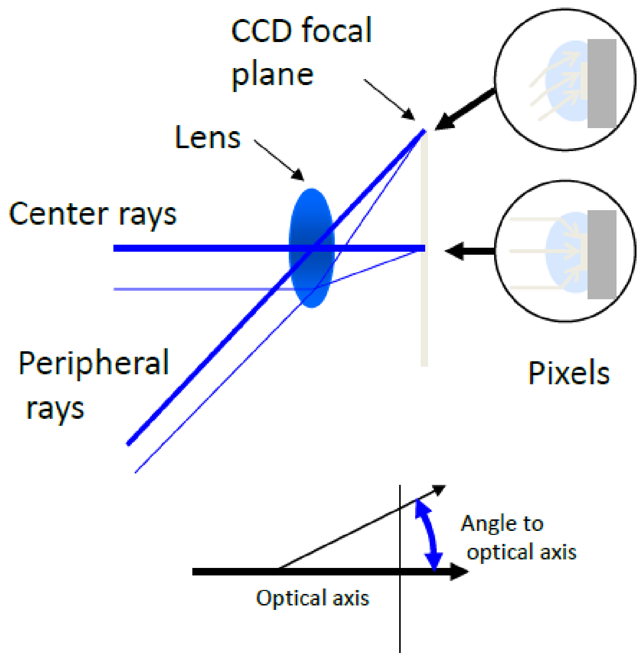
Microlenses

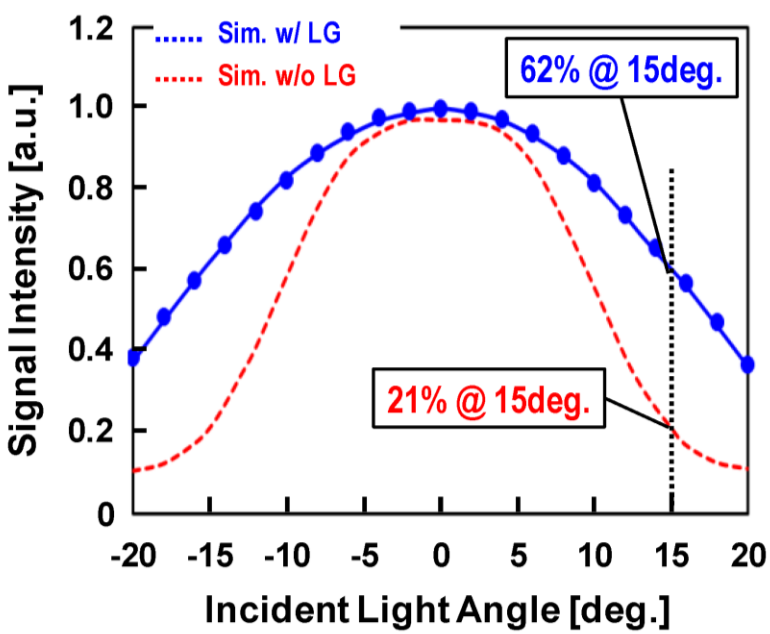


- Microlenses increase the photon collection area of the pixel and focus the photons into the photosensitive area (Good "Fill Factor");
- Almost all modern CCD designs use microlenses (Color&Monochrome);
- Pro – effectively increases the QE of the pixel;
- Con – angular sensitivity to the incident light ray.

Microlenses

Microlenses serve to focus and concentrate light onto the photodiode surface instead of allowing it to fall on non-photosensitive areas of the device





CCD sensors: blooming

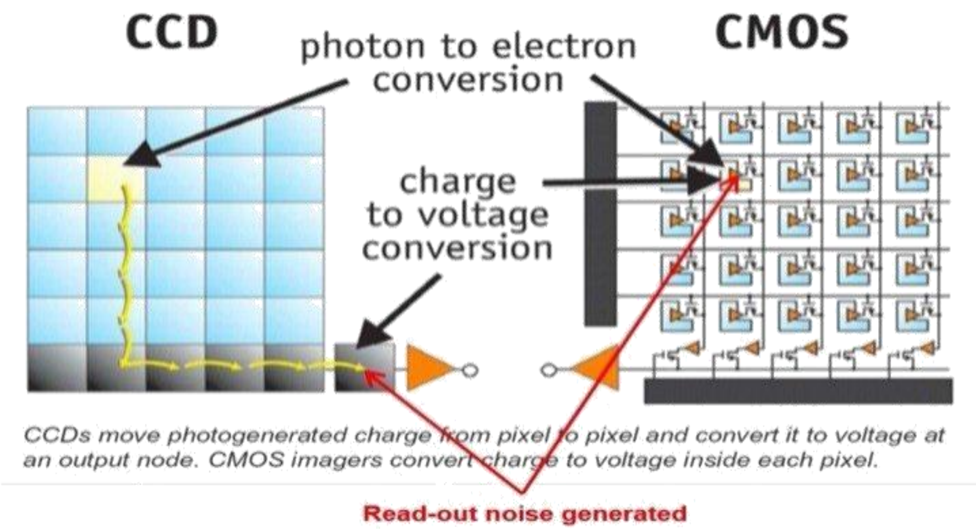
- Blooming is known as the spread of charges to adjacent pixels due to over saturation of pixels;
- This makes some very bright spots in the image.

CCD sensors: smearing

- Smear is similar to blooming. It’s caused by pixels becoming saturated, and light spilling over into the vertical shift register while clocking out.

CMOS sensors

- CMOS Complimentary Metal-Oxide Semiconductor;
- CMOS sensors are voltage-driven devices;



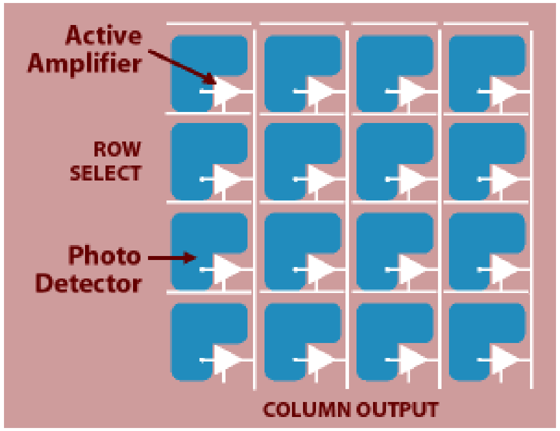
- Light striking the pixel creates a voltage proportional to intensity;
- The voltage is sampled directly at the pixel, digitized on the imager and cleared for the next frame (picture).

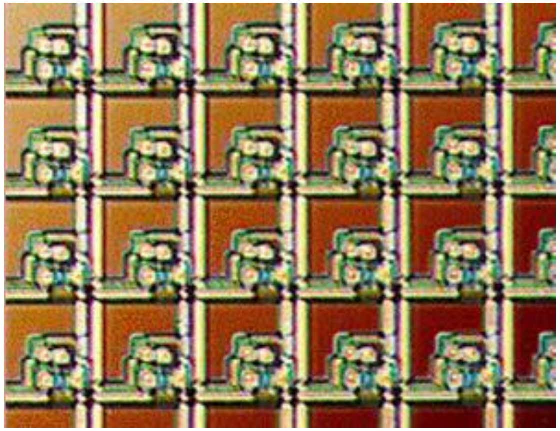
CMOS sensors: sensitivity

CMOS layer stack up prevents using microlens and has lower charge conversion than CCD, usually resulting in lower sensitivity.

Higher Image non uniformities due to unevenness between the individual Pixel cells and multiple A/D circuits in column readout.

CMOS is more resistant to Smearing or Blooming than a CCD.





CMOS sensors: rolling shutter

- An electronic shutter (CCD) or global shutter (CMOS) allow exposure of the whole frame at the same time.
- A rolling shutter will expose the frame line after line. The number of exposures equals the number of lines in the frame.

Image taken with global shutter

Image taken with rolling shutter

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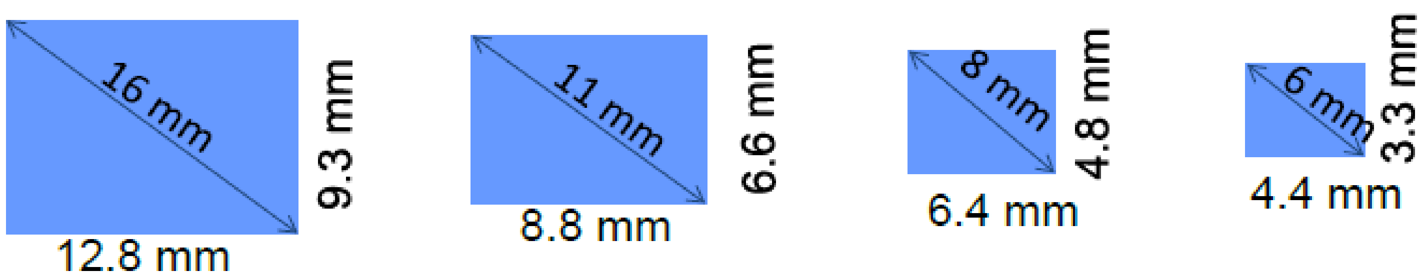
Camera sensors

Image formats:

	1" format	2/3" format	1/2" format	1/3" format
	Type 1	*Type 2/3*	*Type 1/2*	*Type 1/3*
Diagonal:	16 mm	11 mm	8 mm	6 mm

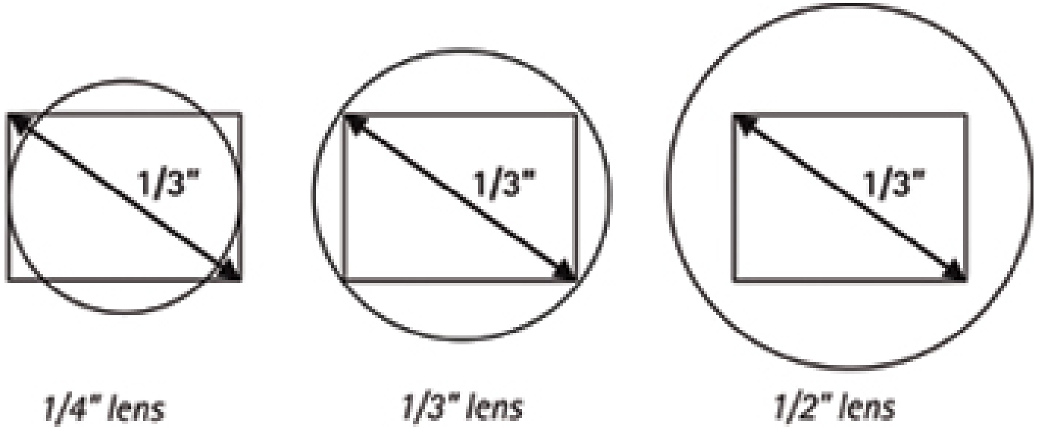
Image size



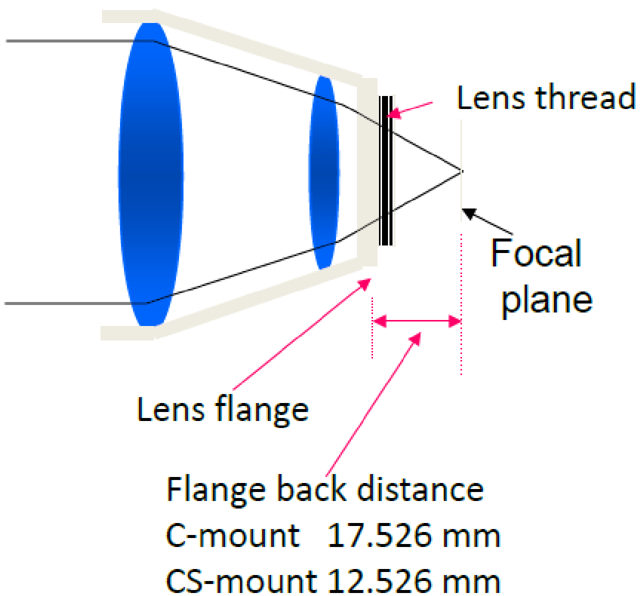
Camera sensors

Lens specs must match image format:

- 1/3" Sensor Format ideally should be paired with 1/3" format lens;
- Larger format lens can be used on smaller sensor;
- Smaller format lens can NOT be used on larger sensor.



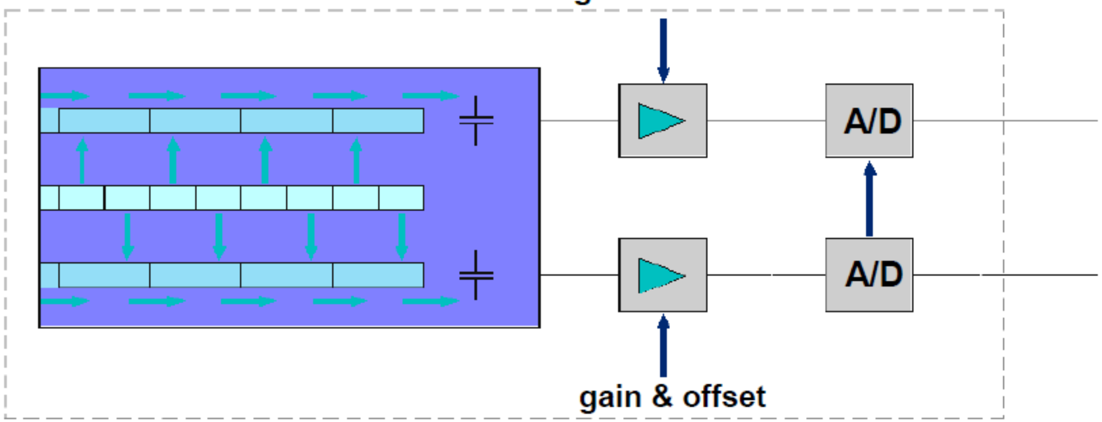
Lens mount: C-mount and CS mount



- The most common lens for CCTV cameras are of the C-mount or CS-mount type.
- The lens thread and the distance from the lens reference flange to the image plane is standard.
- The lens thread is 1-32 UN-2A.
- Diameter is 1 inch.
- The flange back distance in air is 17.526 mm for C-mount. For CS-mount it is 12.526 mm.
- Glass filters or prism between lens and focal plane will increase the distance.

Digital cameras

- Charges from the pixels must be converted first to a voltage. This is done with a capacitor circuit;
- Then the voltage levels must be measured and converted to a number. This is done with the analog to digital converter (A/D);
- Along the way, Gain and Offset can be adjusted before the conversion.

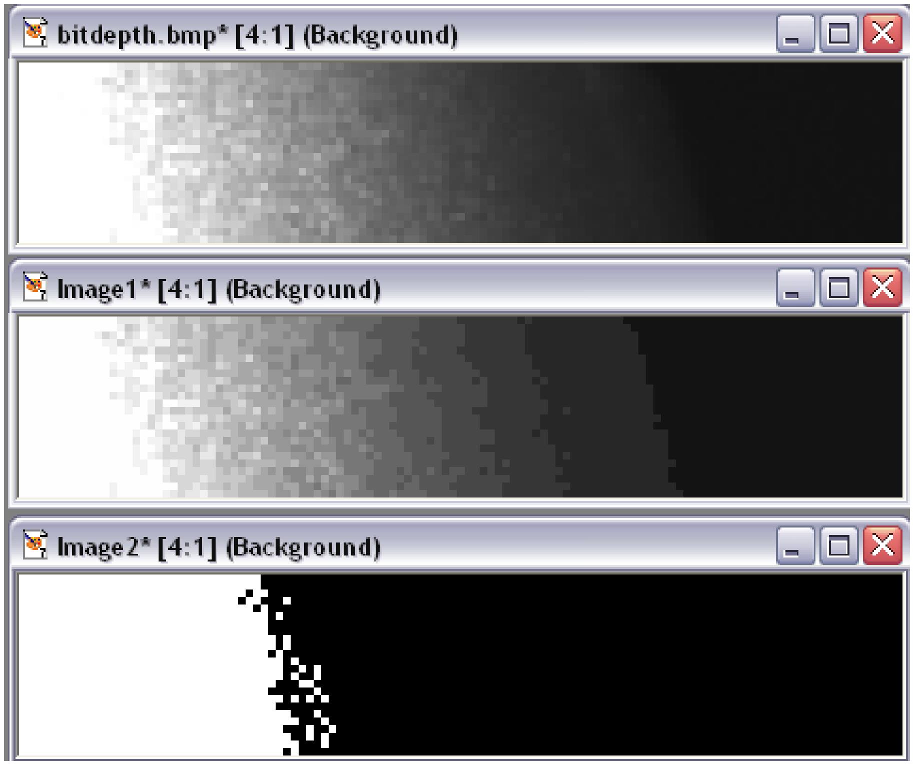


Digital cameras

8-bit image

4-bit image

1-bit image



256 pixel values available

16 pixel values available

2 pixel values available

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Image quality basics

Temporal noise, anything that causes pixel’s value to change over time:

Shot Noise / Photon Noise: Due to random fluctuations in the light. [Brighter/Better Light = less shot noise];

Dark Current Noise: The rate at which electrons are produced due to thermal effects. Every 8° C = Dark noise doubles. [cooler camera = less dark noise];

Quantization Noise: Errors coming from the A/D conversion process [Use a better ADC = less quantization noise].

Image quality basics

Spatial noise: constant non-uniformities in the image caused by:

- Bad sensor design;
- Signal to Noise Ratio (SNR): the ratio of good signal caused by light to unwanted noise. The most important measurement of image quality for digital cameras.

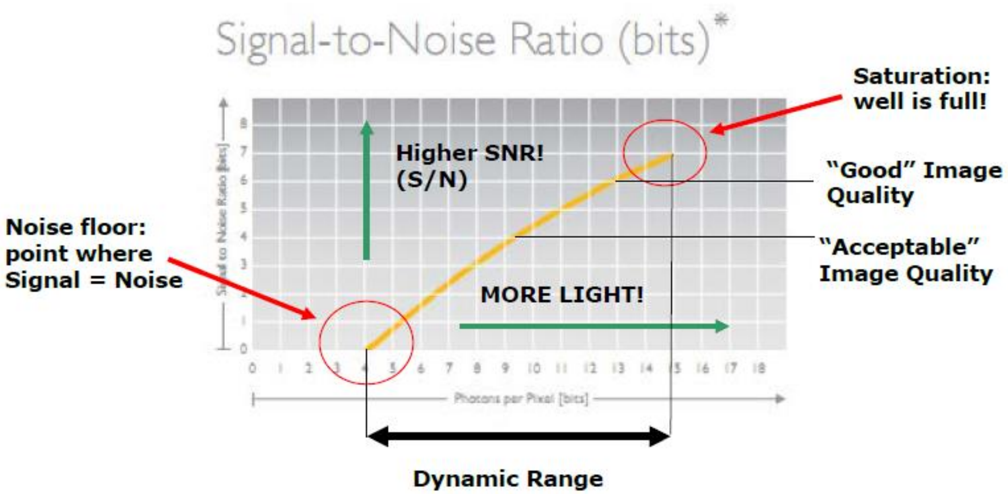


Image quality basics

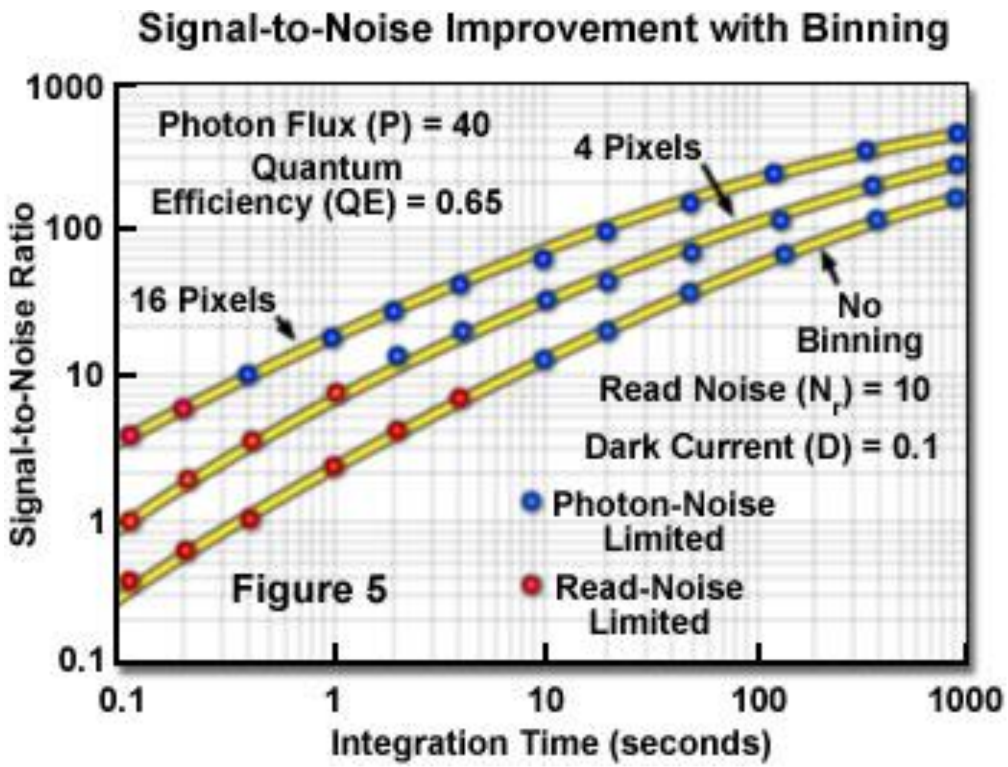


Image quality basics

Dynamic range: The measure of how well a camera can represent details when both bright and dark areas are present.

Low

High

Camera controls

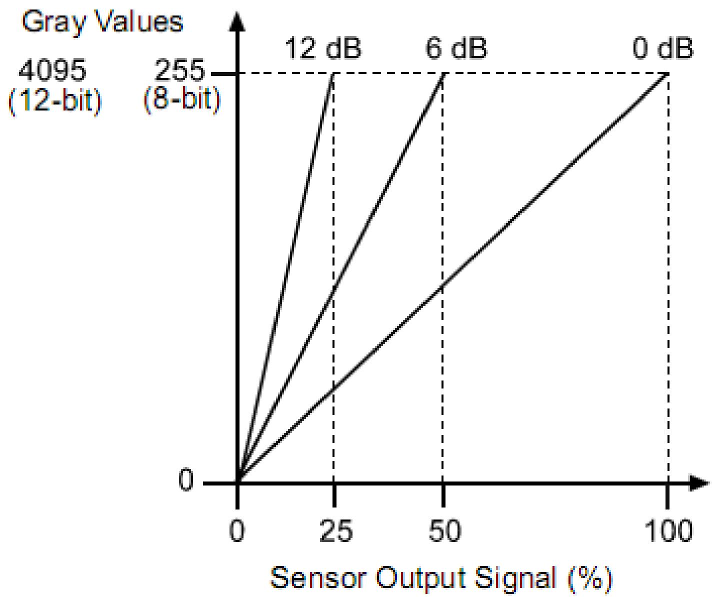
What are some camera controls can we use to affect image quality?

- Gain;
- Exposure;
- Brightness (black level);
- Image format;
- Resolution (array size).

Camera controls: gain

Amplifies analog signal from pixel before conversion.

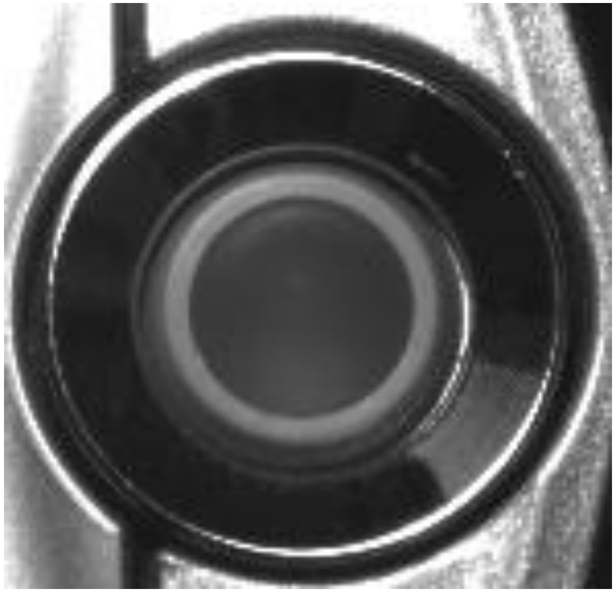
- Pro: Higher Grey Scale level (Brighter)
- Con: Noise introduced (6db gain = 2X increase)



- Increasing gain will increase visibility of both signal and noise!
- Does not increase image quality!
- Use only as a last resort to increase brightness.

Example images of gain effects

High Gain used to compensate for low light. Bright image, but noise is apparent.



Low gain and good lighting is used. Light drowns out noise and makes clean image.

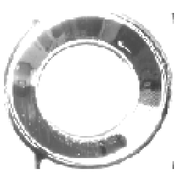
Camera controls: Exposure time

The length of time that the sensor is open for collecting light. Also known as shutter speed and integration time.

Underexposed image: Detail lost in shadows

Good image: Detail is visible

Better image: Good detail and good contrast



Overexposed Image: Detail lost in highlights

- Frame rate may be reduced with increase.
- Motion blur is greater with increase.
- SNR is greatly increased with more exposure (longer shutter time – filling pixel well).

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Camera controls: black level (brightness)

Adds an offset to pixel values.

Adjusting the camera's black level will result in an offset to the pixel values output by the camera. Increasing the black level setting will result in a positive offset in the digital values output for the pixels. Decreasing the black level setting will result in a negative offset in the digital values output for the pixels.

Proper use is to ensure camera accurately measures light when scene is darker.

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Camera controls: black level (brightness)

Low Black Level used. Good Contrast, but some detail is lost in the darker regions (reduced grey level count)

High Black Level used. Contrast suffers, but detail is seen in darker regions (increased grey level count)

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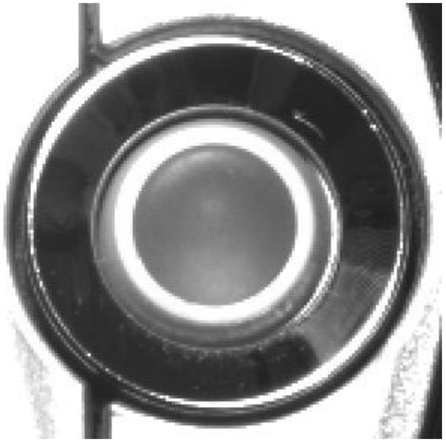
Camera controls: Image format

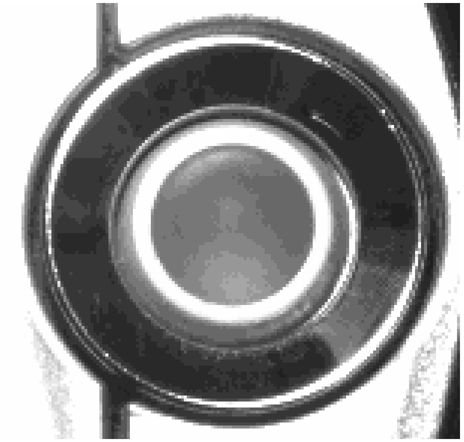
The type of image sent from the camera. Usually specified by color or mono, and then by bit depth.

- Higher bit depth = more data to transmit/process.
- Lower bit depth = loss of detail
- Be wary of anyone wishing to “view” a 12 bit image on a computer monitor. All monitors can *only* display 8 bits or less!
- Many people think they need 12 bits but don’t!

Camera controls: Image format



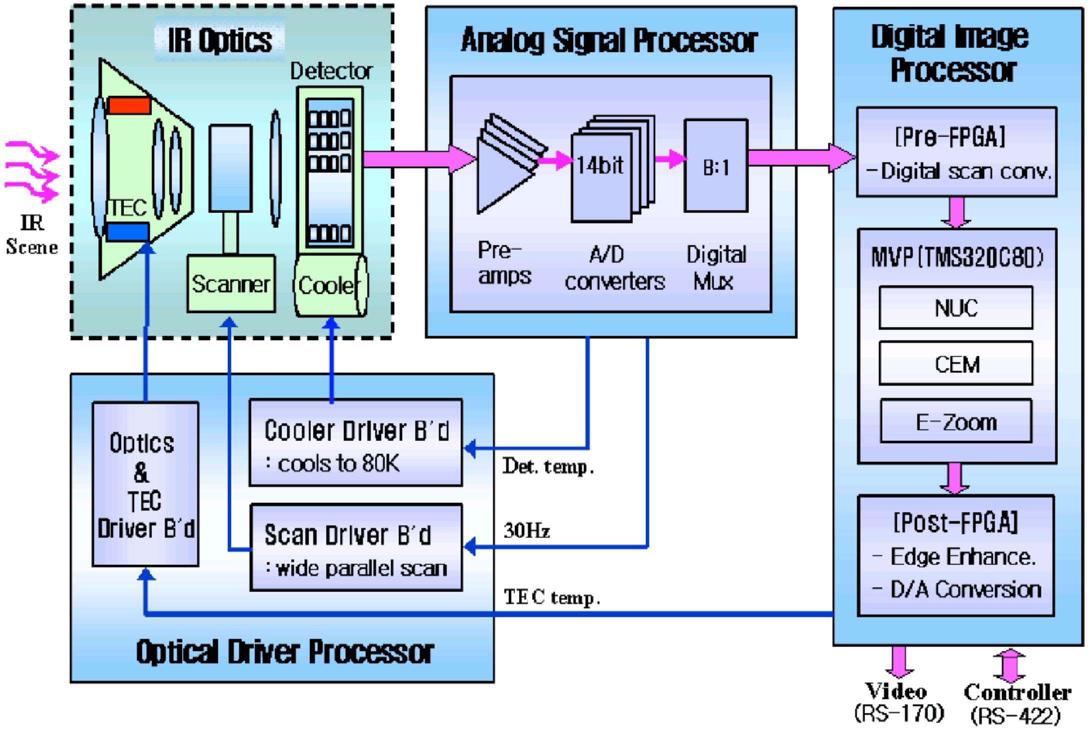
8 bit
88.2 kB/image



4 bit
44.2 kB/image

1 bit
11.3 kB/image

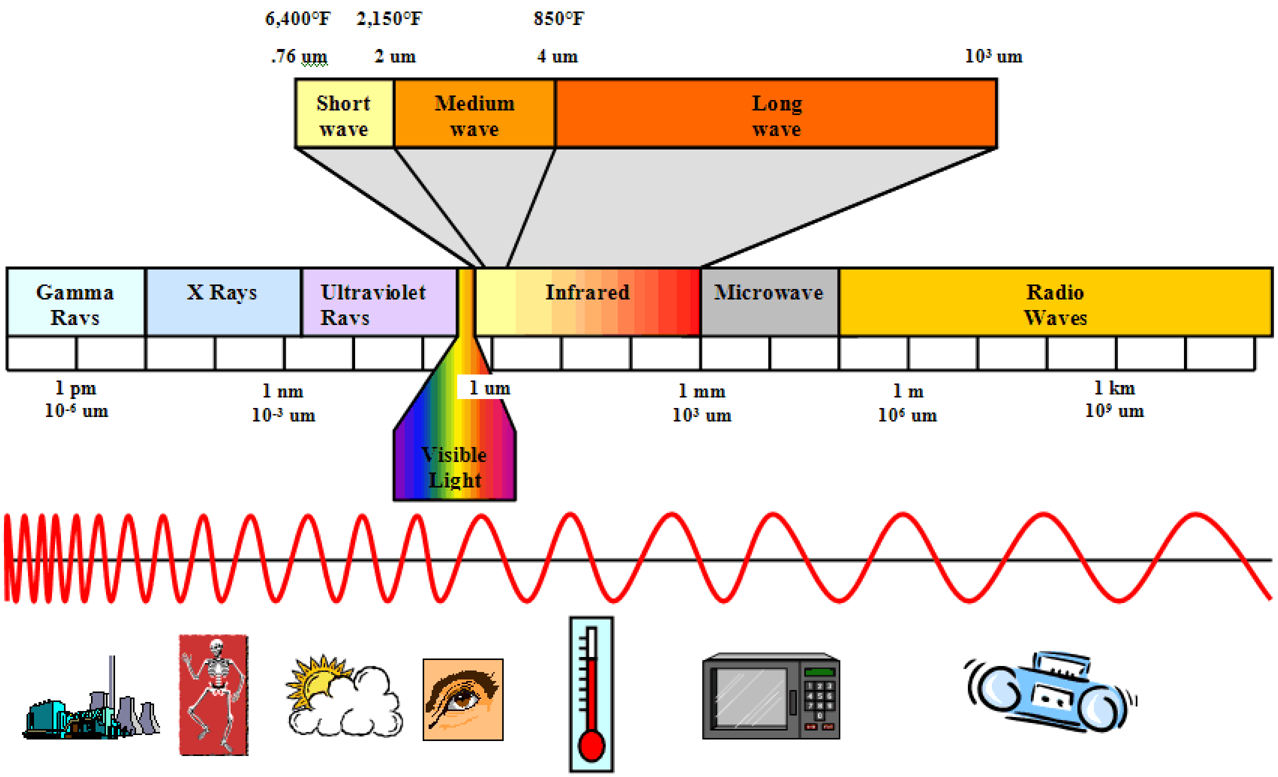
Infrared camera



Infrared energy coming from an object is focused by the optics onto an infrared detector. The detector sends the information to the analog signal processing unit.

This unit translate the data coming from the detector into an image that can be viewed in the viewfinder or on a standard video monitor or LCD screen.

Infrared spectrum



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Reflected and Emitted Light

The energy coming from the target and background is a mixture of reflected and emitted light.

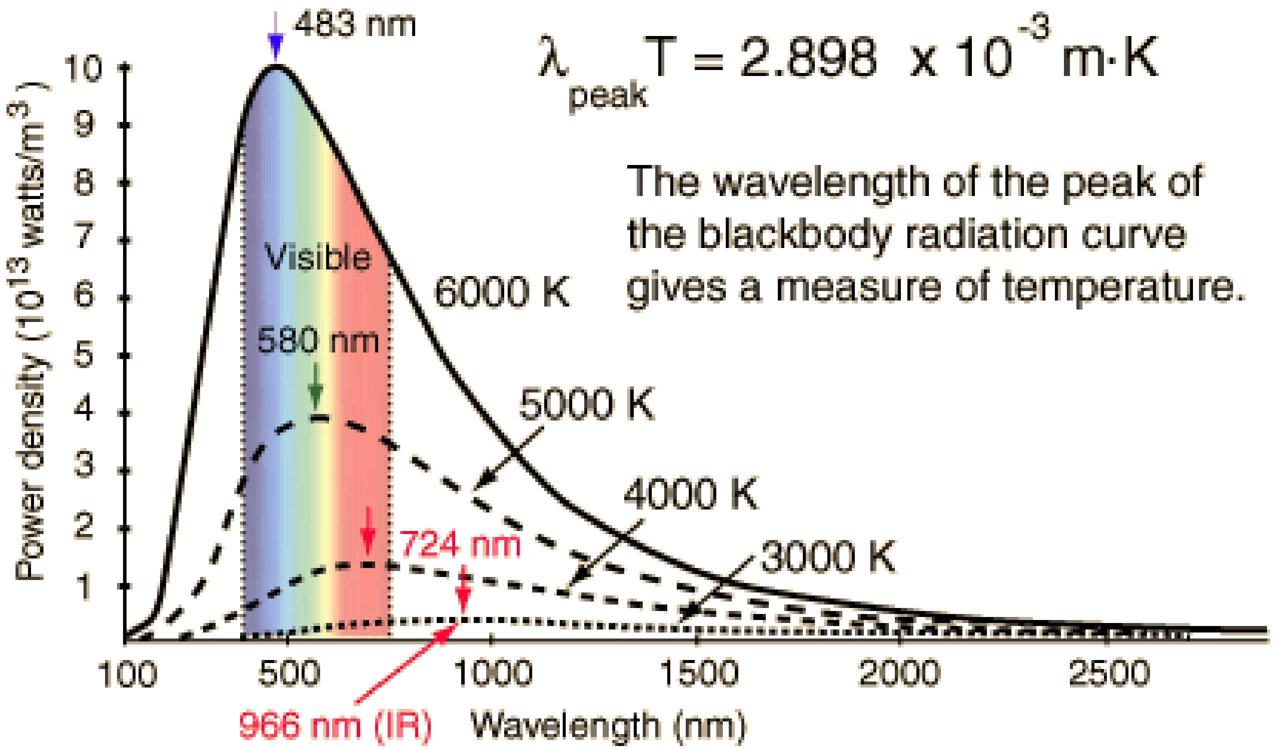
Reflected light is the predominant element for visible sensors but also contributes in near-IR, short wave-IR, and mid-wave IR (it depends on natural or artificial illumination);

With artificial illumination, essentially any wavelength may lead to significant reflection.

Emitted light is a natural feature of all objects: the amount of light radiated and at what wavelengths it is concentrated depends on the temperature and emissivity of the object;

Reflectance and emissivity vary with wavelength (snow is highly reflective in the visible but highly emissive in the IR.

Black-body Radiation



λ_{peak} vs Temperature

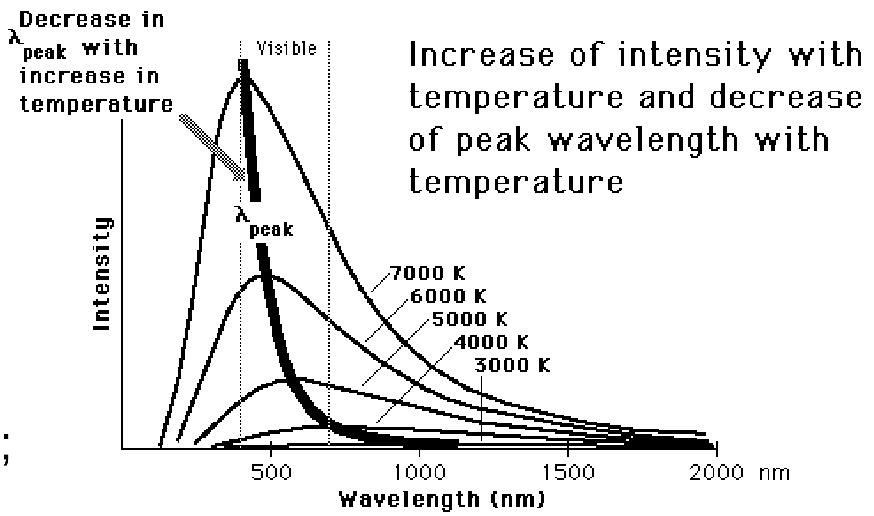
$$\lambda_{peak} = \frac{2.9 \times 10^{-3}}{T}$$

310 K (body temperature)

$\lambda_{peak} = \frac{2.9\times10^{-3}}{310} = 9\ \mu m$ (infrared light);

5800 K (Sun's surface)

$\lambda_{peak} = \frac{2.9\times10^{-3}}{5800} = 500\ nm$ (visible light);



Type of thermal imaging cameras

COOLED THERMAL IMAGER

- Cooled detectors are typically contained in a vacuum-sealed case and cryogenically cooled;
- Cooling is necessary for the operation of the semiconductor materials used else they would be blinded by their own radiation;
- Cooled infrared cameras provide superior image quality;
- Bulky and expensive to produce and run;
- Cooling is power-hungry and time-consuming hence the camera needs time to cool down before it can begin working again.

UNCOOLED THERMAL IMAGER

- Un-Cooled detectors use a sensor operating at ambient temperature, or a sensor stabilized at room temperature using control elements;
- Resolution and image quality tend to be lower than cooled detectors;
- Smaller and less costly to produce and run;
- Fast operation and low power consumption.

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Uncooled vs cooled thermal cameras

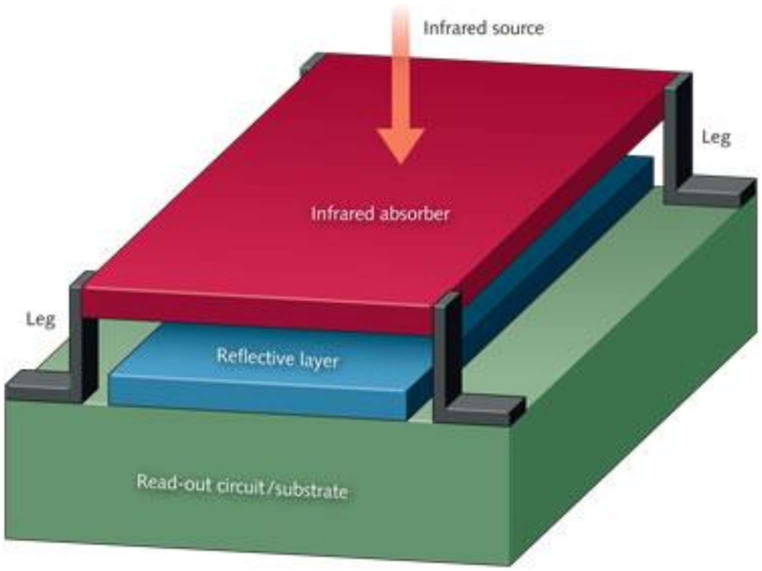
Uncooled

Cooled

Uncooled thermal sensors

A microbolometer consists of an array of pixels, each pixel being made up of several layers.

The bottom layer consists of a silicon substrate and a readout integrated circuit. Electrical contacts are deposited and then selectively etched away. A reflector, for example, a titanium mirror, is created beneath the IR absorbing material. Since some light is able to pass through the absorbing layer, the reflector redirects this light back up to ensure the greatest possible absorption, hence allowing a stronger signal to be produced.



Uncooled thermal camera: calibration

- Non-uniformity correction, which refers to the different operating points of the individual pixels of a microbolometer.
- Defective pixel correction, which refers to pixels that either do not work or whose parameters vary greatly from the mean.
- Shutter correction, which refers to the correction required due to the radiance of the camera interior that also varies with sensor temperature. Current uncooled thermal cameras perform an automatic shutter correction based on the time or change in sensor temperature.
- Radiometric calibration, which refers to establishing the relationship between the response of the sensor and the temperature of the object. It is possible to approximate the sensor output signal with a Planck curve.
- Temperature dependence correction, which refers to the effect of the sensor temperature on the response of the sensor. A linear correction that considers the signal from the object and the signal from the camera (dependent on camera temperature) is typically used to perform this type of correction.

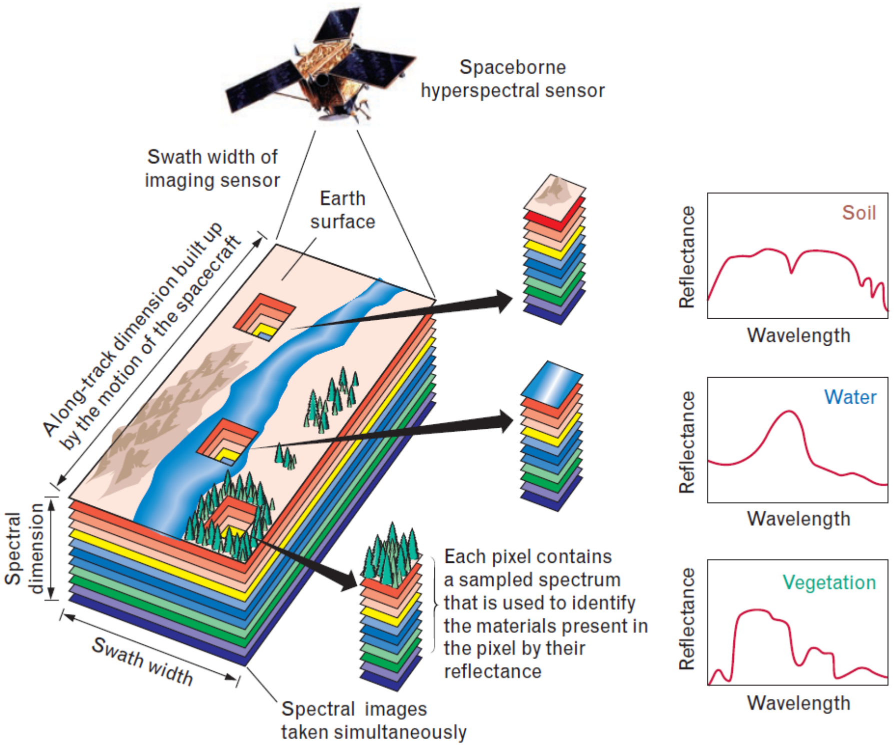
Fundamental of Spectral Imaging

- **Irradiance** refers to the light energy per unit time (power) impinging on a surface, normalized by the surface area (W/m^2);
- **Reflectance** is a unitless number between 0 and 1 that characterizes the fraction of incident light reflected by a surface. Reflectance may be further qualified by parameters such as the wavelength of the reflected light, the angle on incidence, and the angle of refection;
- **Radiance** is the irradiance normalized by the solid angle (in steradians) of the observation or the direction of propagation of the light (W/m^2/steradian).

Th concept of imaging spectroscopy

An airborne imaging sensor simultaneously samples multiple spectral wavebands over a large area in a ground-based scene.

After appropriate processing, each pixel in the resulting image contains a sampled spectral measurement of reflectance, which can be interpreted to identify the material present in the scene.



Reflectance spectrum

The color and reflectivity of an object are typically important indications of the material composition of the object.

The reflected light or spectral radiance, $L_s(\lambda)$, is given by:

$$L_s(\lambda) = \rho(\lambda) \cdot L_i(\lambda)$$

where $L_i(\lambda)$ is the impinging scene radiance and $\rho(\lambda)$ is the material reflectance spectrum.

Since the reflectance spectrum is independent of the illumination, it provides the best opportunity to identify the materials in a scene by matching the scene reflectance spectra to a library of known spectra.

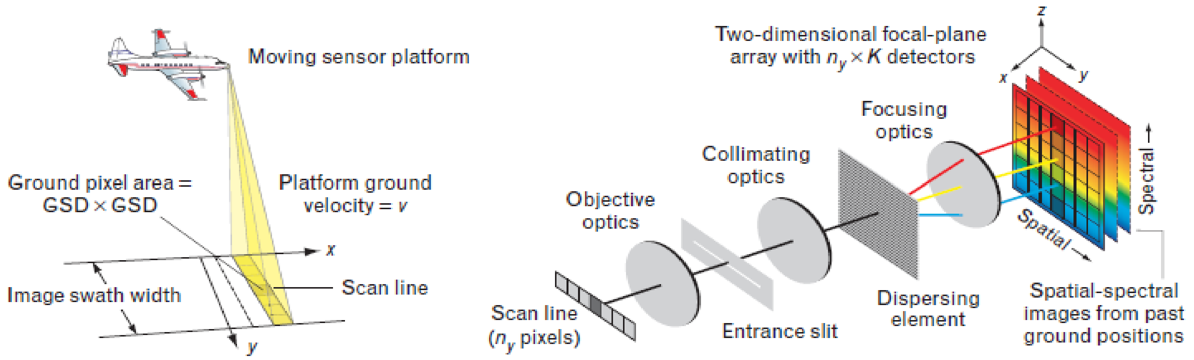
In case of solar illumination, the spectral irradiance of the light reaching the ground level should be well characterized (it depends on the atmospheric conditions).

Sampling operations

There are four sampling operations involved in the collection of spectral image data: spatial, spectral, radiometric, and temporal.

Spatial resolution is the ground sample distance (GSD).

GSD varies from a fraction of a meter to tens of meters and is established primarily by the sensor aperture and platform altitude.

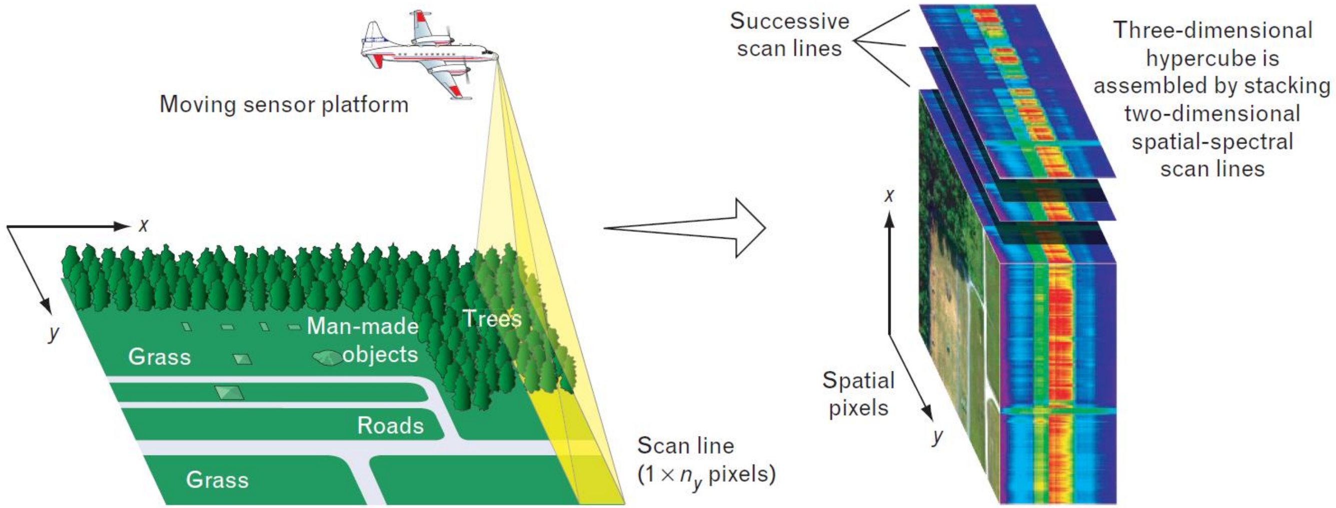


Sampling operations

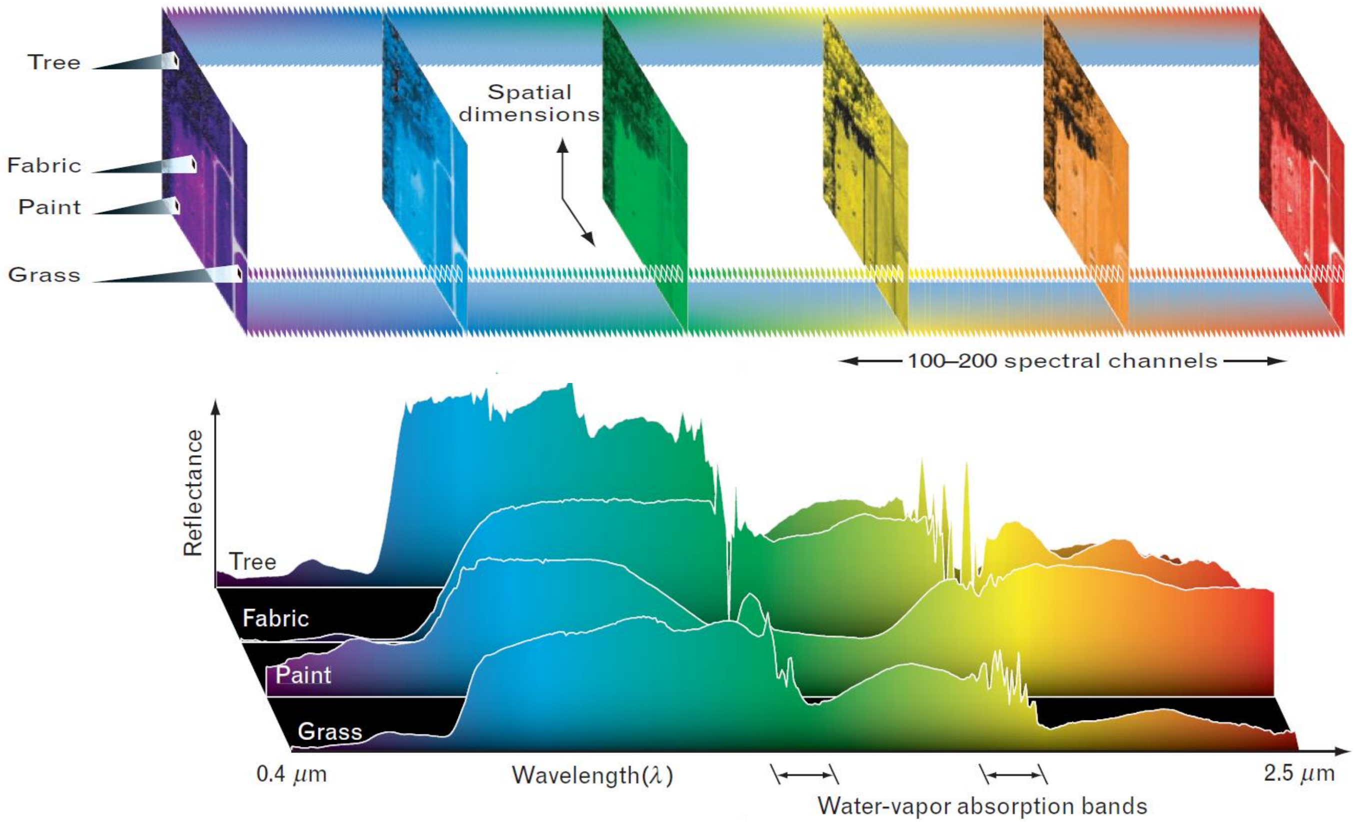
The spectral sampling is achieved by decomposing the radiance received in each spatial pixel into a finite number of wavebands.

The wavebands may vary in resolution, and may be overlapping, contiguous, or disparate, depending upon the sensor design;

An analog-to-digital converter samples the radiance measured in each spectral channel, producing digital data at a prescribed radiometric resolution.

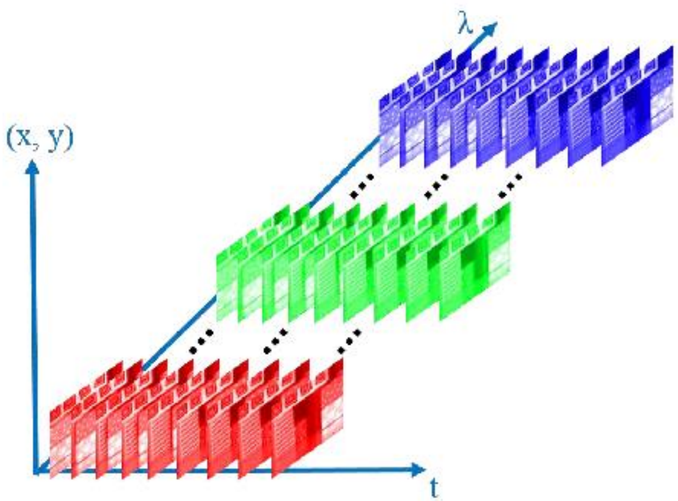


Sampling operations



Sampling operations

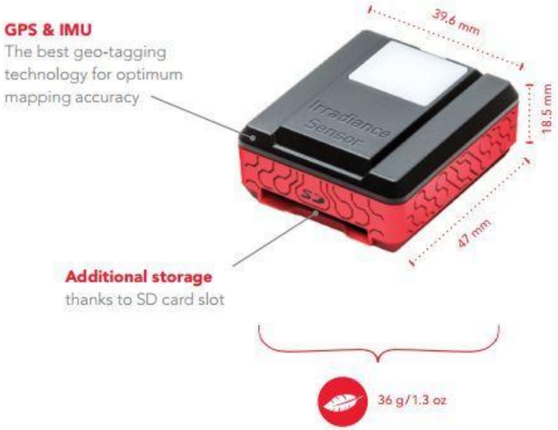
- While there is an integration time associated with the image formation process, the term temporal sampling refers not to the time associated with image formation, but to the process of collecting multiple spectral images of the same scene separated in time;



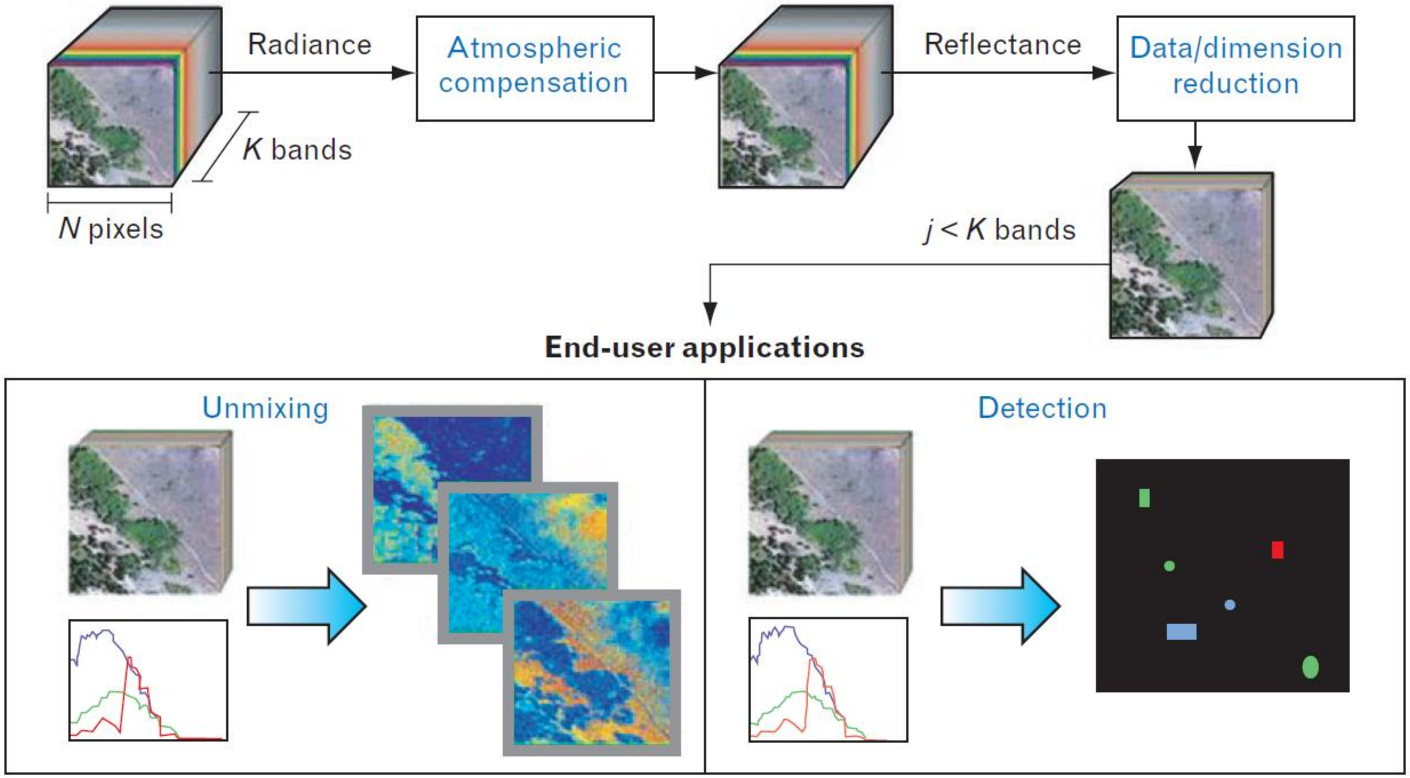
Practical issues

- Spatial resolution: reducing aperture size reduces sensor cost but results in degraded spatial resolution.
- Atmospheric effects: the atmosphere modulates the spectrum of the solar illumination before it reaches the ground, and this modulation must be known or measured in order to separate the spectrum of the illumination from the reflectivity that characterizes the materials of interest in the scene.
- Spectral variability: variability in the reflectance spectrum of the materials.

Example of multispectral camera



Spectral processing diagram



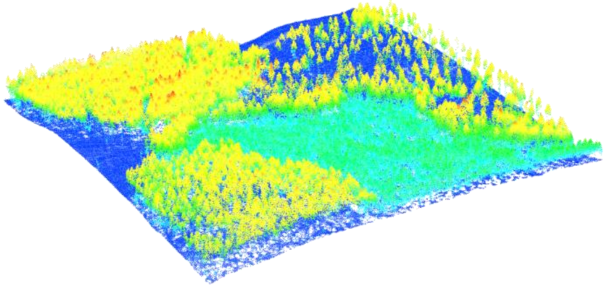
LiDAR

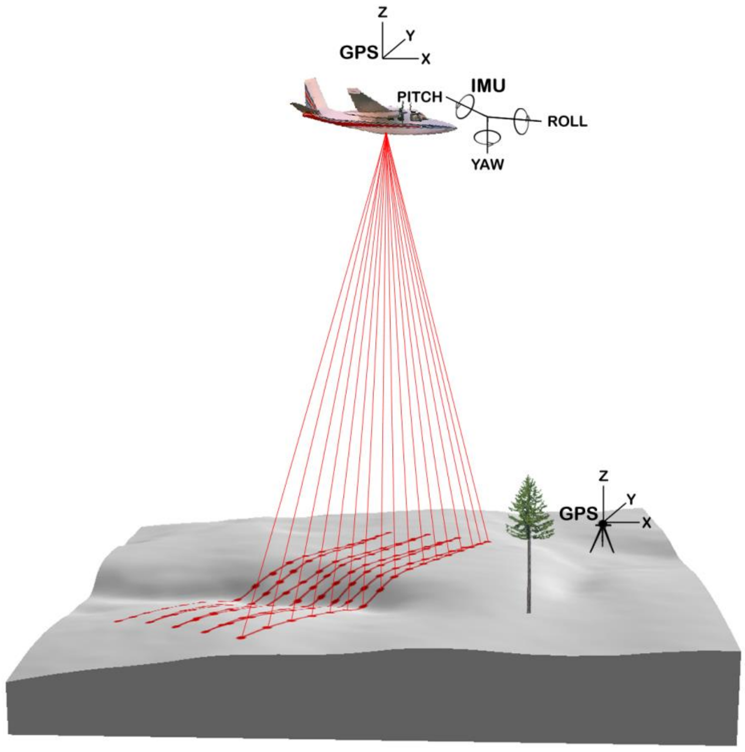
- LiDAR stands for Light Detection and Ranging;
- Laser generates an optical pulse
- Pulse is reflected off an object and returns to the system receiver
- High-speed counter measures the time of flight from the start pulse to the return pulse
- Time measurement is converted to a distance (the distance to the target and the position of the airplane is then used to determine the elevation and location)
- Multiple returns can be measured for each pulse
- Up to 200,000+ pulses/second

Aerial LiDAR System Components

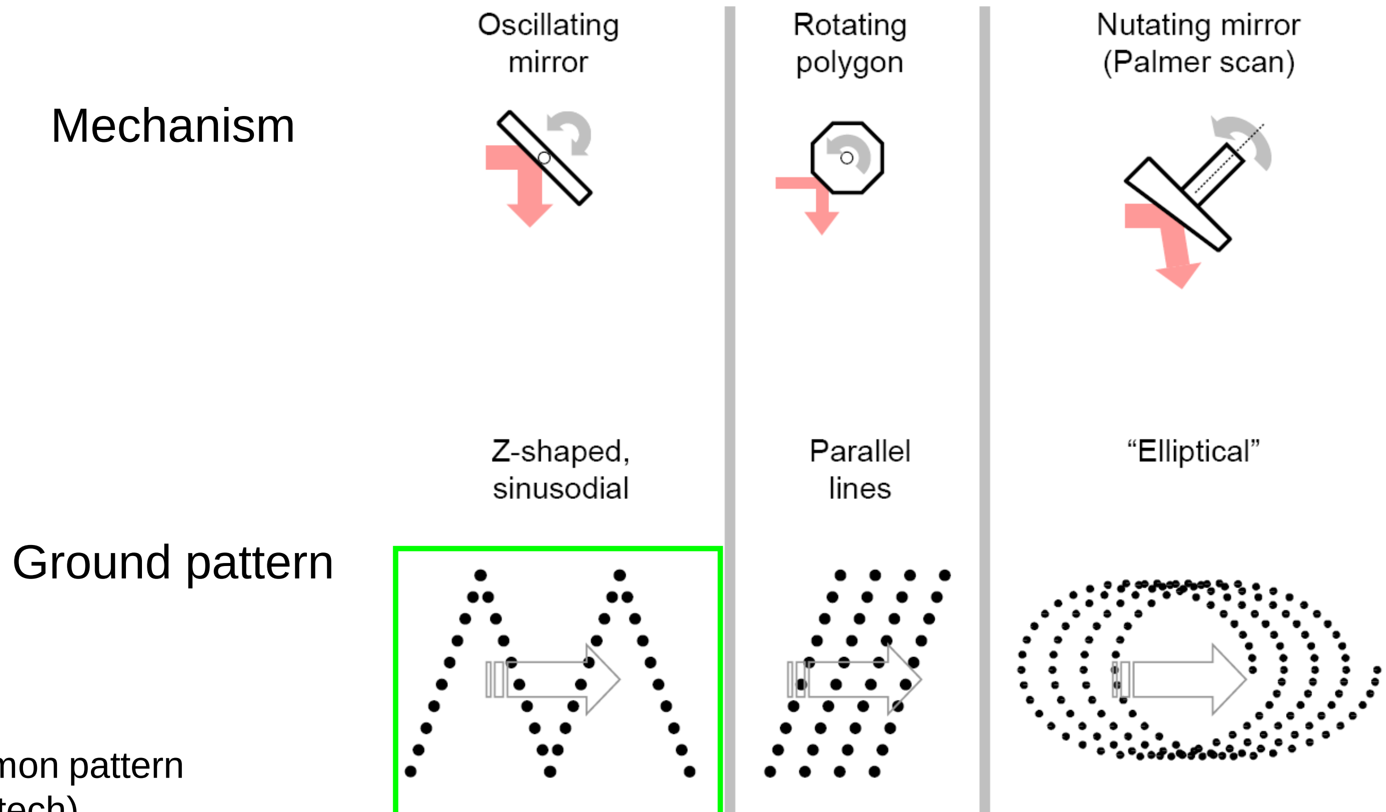
- Aircraft
- Scanning laser emitter-receiver unit
- Differentially-corrected GPS
- Inertial measurement unit (IMU)
- Computer

LiDAR point data colored by height





Scanning mechanisms



Most common pattern
(Leica, Optech)

Reflectivity

- Highly reflective objects may saturate some laser detectors, while the return signal from low-reflectivity objects may occasionally be too weak to register as valid
- Minimum detectable object size depends on reflectivity
- A strong sunlight reflection off a highly reflective target may "saturate" a receiver, producing an invalid or less accurate reading

MATERIAL	REFLECTIVITY @ λ = 900 nm
Dimension lumber (pine, clean, dry)	94%
Snow	80-90%
White masonry	85%
Limestone, clay	up to 75%
Deciduous trees	typ. 60%
Coniferous trees	typ. 30%
Carbonate sand (dry)	57%
Carbonate sand (wet)	41%
Beach sands, bare areas in desert	typ. 50%
Rough wood pallet (clean)	25%
Concrete, smooth	24%
Asphalt with pebbles	17%
Lava	8%
Black rubber tire wall	2%

Source: www.riegl.co.at

Dust & Vapor

- Laser measurements can be weakened by interacting with dust and vapor particles, which scatter the laser beam and the signal returning from the target
- Systems that are expected to work in such conditions regularly can be optimized for these environments.