Optical resolution improvement flying at Very Low Earth Orbit (VLEO)

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Abstract

Flying at Very Low Earth Orbits (VLEO), below 450 km, involves several advantages. One of them is the increase of the optical resolution (both angular and spatial resolution). The aim of this work is to carry out a study of how the resolution is affected by the altitude. Resolution is defined as the ability of a system to reproduce an object which has been observed. The more similar to the original the image is, the better resolution the system will have. In this work, the angular resolution, the spatial resolution and the improvement produce by the orbital decrease are analyzed. Some software enhancing resolution techniques are also studied. This study is being part of the DISCOVERER H2020 European Project: ID 737183. ***Keywords: LEO, VLEO, Resolution, Angular resolution, spatial resolution, Airy Disc, Rayleigh criterion, Orbit, Altitude, Satellite, Image Restoration, Pan-sharpening, SuperResolution.***

1. Angular and Spatial Resolution

The angular resolution is the capability of the system to resolve separate points that are located at an angular distance. The optical resolution can be defined as the ability to resolve remote objects at a short distance and reproduce them into individual elements of the image. This performance is characterised by the Rayleigh criterion, which states that the minimum separation between two points of light to be distinguished by an observer is the radius of the Airy Disc, which is defined as:

$$r = 1.22\,\frac{\lambda}{D}$$

where D is the aperture (mm) and λ is the wavelength (mm).

Considering the telescope as optical system, r is equivalent to the angular resolution, since we can consider diffraction through a circular aperture.

Regarding to Earth Observation we can define the angular resolution as the Ground Resolution Distance (GRD):

$$GRD = 1.22\,\frac{H \cdot \lambda}{D}$$

where D is the aperture (mm), H is the altitude (m) and λ is the wavelength (mm). See Figure 1.

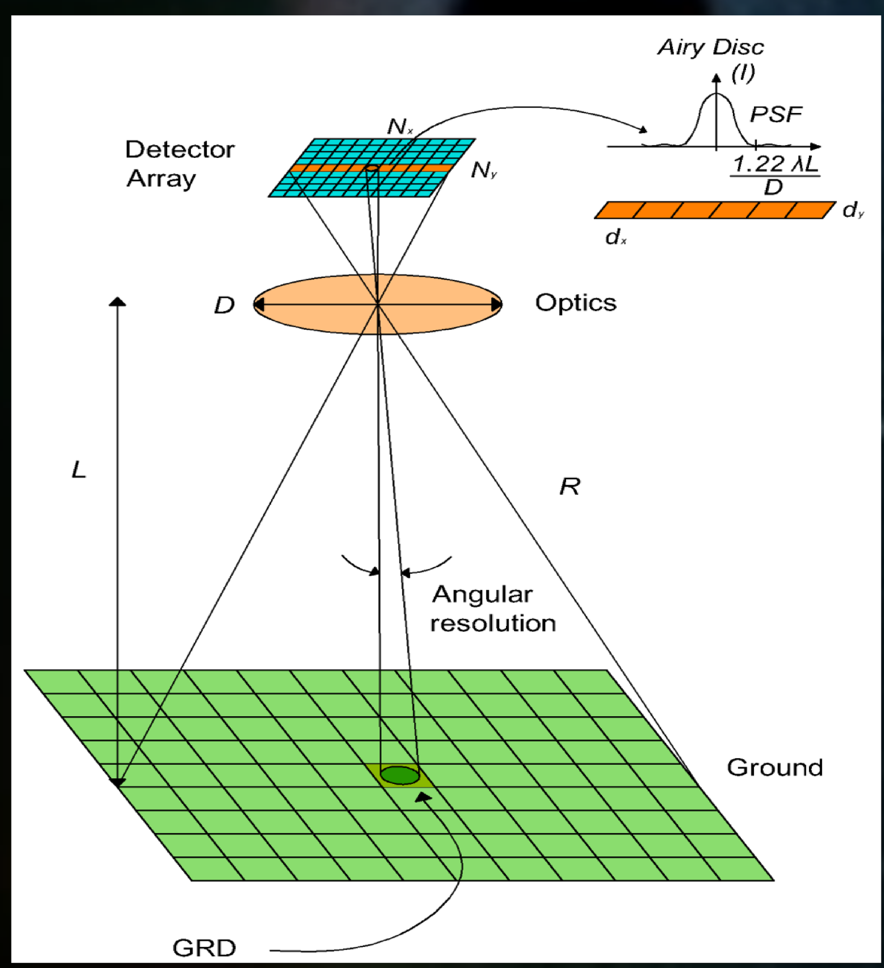

Figure 1: Ground Resolution Distance outline

Spatial resolution is related to the number of pixels that are used to reproduce the image. The more pixels are used, the better quality the image will have.

Regarding Earth Observation we define the spatial resolution as the Ground Sample Distance (GSD).

GSD is the geometrical projection of a single pixel on ground (see Figure 2.). Mathematically GSD is defined as:

$$GSD = \frac{d \cdot H}{F}$$

where d is the pixel size (mm), H is the altitude (m) and F is the focal length (mm).

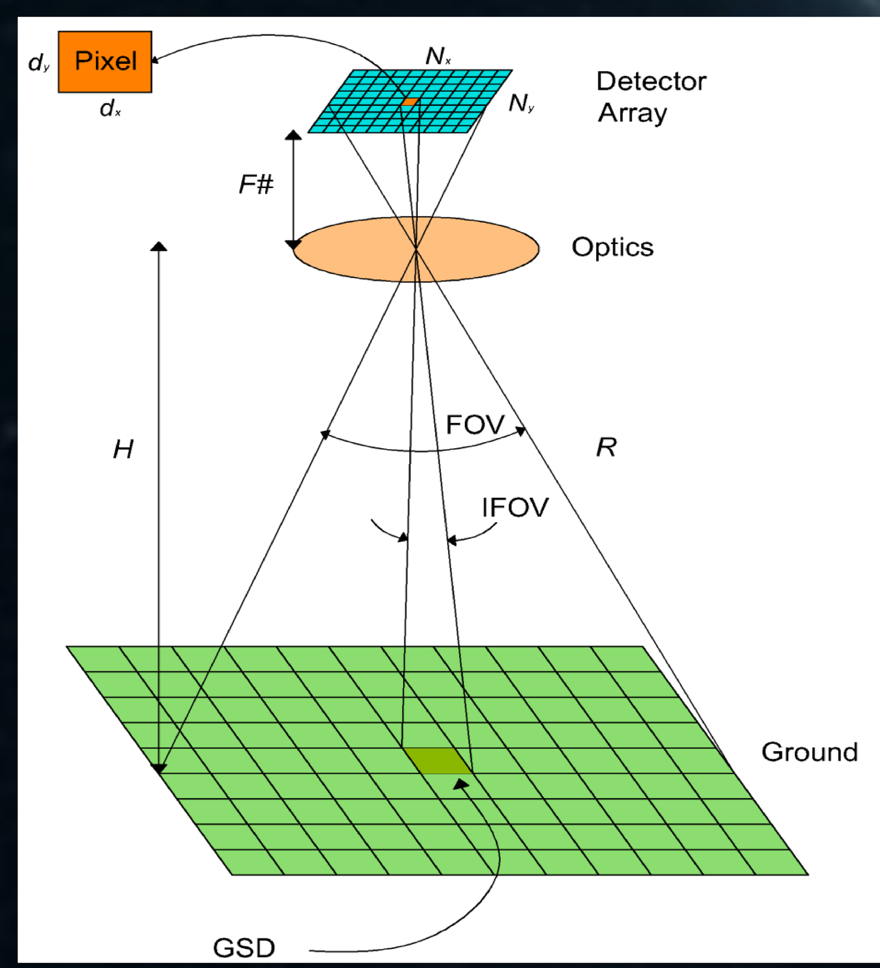

Figure 2: Ground Sample Distance outline

Example: Calculate GRD and GSD by considering a range of altitudes between 400 km and 600 km:

Table 1: Calculation of GRD and GSD

Optical configuration:

d = 5.5 10^{-6} m
F = 4500 10^{-3} m
λ = 0.650 10^{-3} m
D = 0.5 m

CALCULATION OF GRD AND GSD PARAMETERS					
Altitude (m)	400000	450000	500000	550000	600000
GRD (m)	0.63	0.71	0.79	0.87	0.95
GSD (m)	0.49	0.55	0.61	0.67	0.73

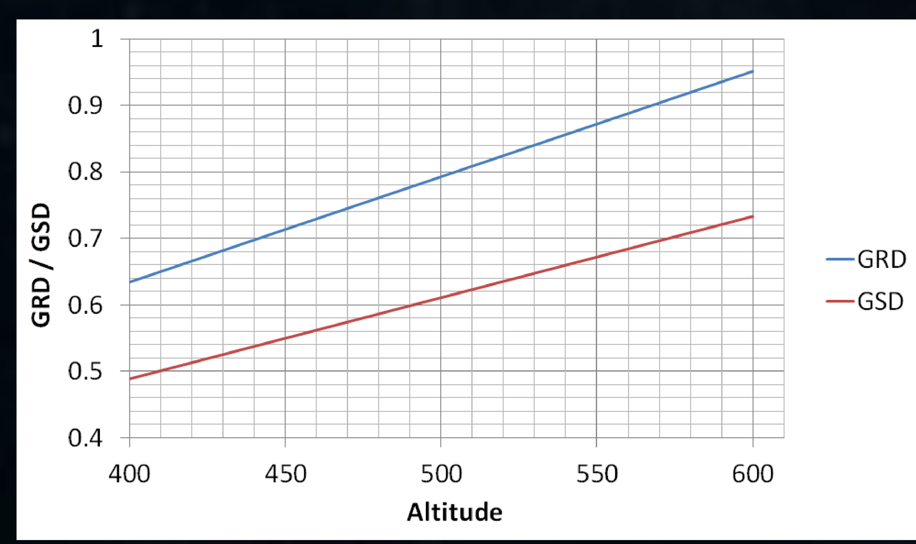

Figure 3: Resolution variation with Altitude

2. Enhancing resolution techniques

The direct manner to enhance the resolution is a hardware modification: i) Increase the aperture of the telescope, ii) Decrease the pixel size and iii) Decrease the altitude. However, all these actions have consequences in the design of the optical payload: increment in the optical system weight and degradation of the signal to noise ratio, among others. For these reasons, other post-processing techniques in order to improve the resolution have been studied: Image Restoration, Pan-Sharpening and SuperResolution.

IMAGE RESTORATION

Image restoration aims at improving the quality of the panchromatic image by reducing or balancing the degradations produced in the image acquisition chain. Image restoration consists of two stages: deconvolution and denoising. The output is a sharper panchromatic image. See Figure 4.

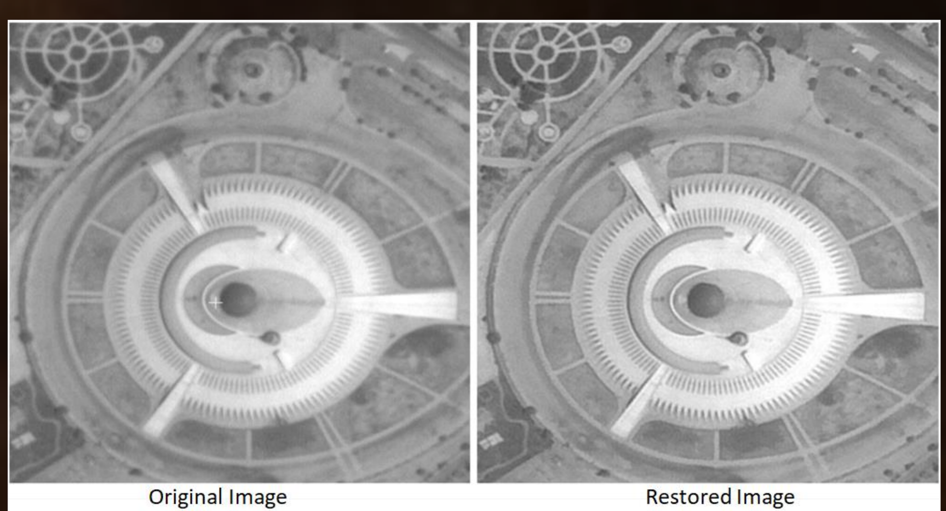

Figure 4: CartoSat-2A Image Restoration [3]

PAN-SHARPENING

The optical systems typically produce high resolution panchromatic images and multispectral images with lower resolution. The purpose of the pansharpening techniques is to produce multispectral images with the same resolution of the panchromatic band by fusing together the panchromatic and multispectral bands. The output is a multispectral image with an enlarged resolution (Figure 5).

Figure 5: WolrdView-2 Pan-Sharpening[4]

SUPERRESOLUTION

Super-resolution techniques consist of building a higher spatial resolution image by merging several images with lower spatial resolution. Image processing algorithms can improve the spatial resolution by combining the non-redundant information included in the lower resolution images. Super resolution techniques also boost image signal-to-noise ratio (SNR). The output is an image with higher spatial resolution and improved image quality (Figure 6).

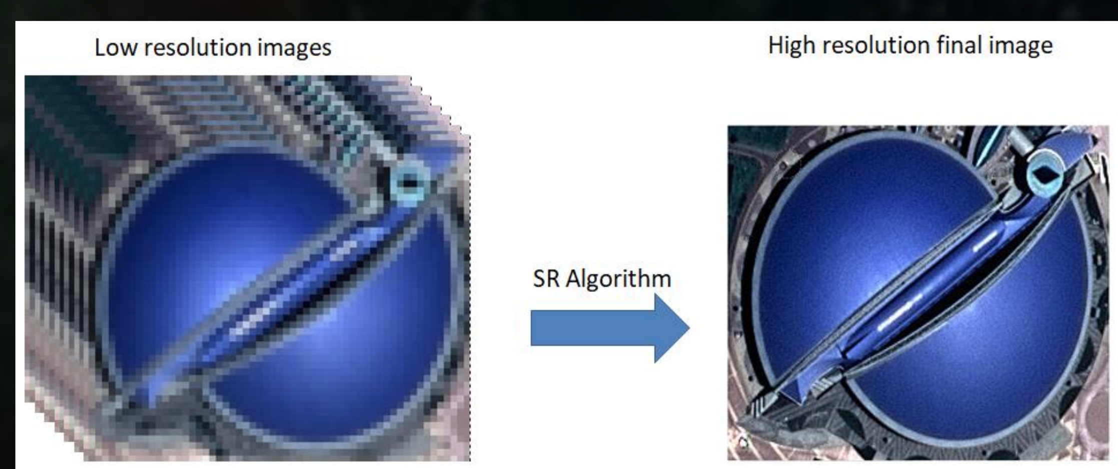

Figure 6: SuperResolution example: Deimos-2 data

3. Conclusions

There are several advantages by flying at VLEO, such as the increase radiometric performances, low risk of collision with space debris and increase geospatial accuracy. One of the main advantage is the increase of the optical resolution. In this work we show that flying at very low altitude is a direct process to increase the resolution (Figure 3). This result is in line with the purpose of DISCOVERER project. Other ways to improve the resolution can also be used instead of modifying the physical parameters of the payload.

4. References

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