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INTRODUCTION TO IMAGE QUALITY DEFINITION AND REQUIREMENTS FOR REMOTE SENSING SATELLITES

Abstract

This presentation attempts to show how important the needs for image quality are in the definition of an image-taking satellite system and the associated on-board/ground processing facilities.

The way in which image quality is defined and checked, as well as the different quality levels envisaged in the framework of the future ESA remote sensing systems, are presented.

1. INTRODUCTION

A spacecraft and its instruments constitute one element of a whole chain which normally includes considerable ground data treatment. Image data contain quantitative information not always accessible by direct visual interpretation.

In general, the more refined the interpretation process, the more demanding the quality requirements of the data are.

The products generated by remote sensing satellites are images produced by passive means (scanner, push-broom, optical or microwave radiometer), or active means (Synthetic Aperture Radar, LIDAR).

Recent developments in image data analysis demonstrate that the limit of thematic interpretation is in general strongly related to the quality of picture amplitude and geometry. The monitoring of these features has now become essential. Visual inspection is rapidly found to be inadequate for this quality control and hence automated processing is necessary to monitor the quality of large-scale production batches as envisaged for the new generation of ESA remote sensing satellites.

This raises three principal questions:

- How to define image quality,
- How to measure the quality of the raw satellite picture,
- How to control the quality of processed pictures.

This presentation will specifically cover the first item.

2. DEFINITION OF IMAGE QUALITY FACTORS (refer to Figures 1, 2)

The hierarchy of quality parameters is given in the break-down structure of Figure 1. Each of these parameters is described below with three successive levels of complexity. This picture quality definition can be applied to different types of products which are also defined below.

Image Quality (Level a)

A picture is simply a matrix of measurements which convey two types of information: the value of the measurement (the quality of which is called amplitude quality), and the relationship between the coordinates of the value in the matrix and its ground coordinates (or any other kind of surface coordinate definition). The quality of the knowledge of this second relationship is called geometrical quality.

In some circumstances, these two parameters are linked (in some processing such as rectification, interactions between amplitude and geometry can occur) but such effects are so limited that they are not worth considering at the present level of definition.

Image Quality (Levels b, c)

. Geometrical quality

A first characteristic of the picture is the definition of its size. It is not a direct quality criterion but it can be considered as such, because the higher the number of pixels, the higher the information content. The parameter is called picture size definition. In some cases such as the Landsat continuous scanning system, the line size is the only sensible element, but even in this case, as soon as processing occurs, the data stream has to be cut and automatically leads to a size definition.

This size can be given in terms of number of pixels/line, number of lines per picture when appropriate, and number of spectral channels per scene.

The local quality of a picture is related to the differential properties of this picture. An easy way to assess the local quality is to monitor a small area (typically less than 10 pixels) and examine its properties.

A first parameter concerns the response to the point-spread function input.

This response is relatively sharp and this factor is closely related to a value "MTF" (Modulator Transfer Function) which is the electro-optical equivalent of frequency response in signal processing.

If the positioning of a given pixel is not absolutely regular, it may lead to difficulties in the interpretation of the data. This spatial variation has to be avoided as far as possible (pixel jitter).

Another element to take into account is the local properties of superimposition of pictures either from different sensors, channels or instruments. The registration parameters which describe the shift of different pictures have to be kept negligible or be perfectly known.

As soon as measurements have to be referred to a specific ground position, the differences between the actual image and the reference one have to be minimised. The reference image is a synthetic picture description which is not necessarily a plane one but can also be a geographical projection or any other type of 'a priori' description.

A vector describing the shift between reference and actual images can be associated with each pixel. This vector field is called a deformation field and characterises the distortion of a picture.

Depending on the spatial wavelength associated with the distortion law, one can define the HF (High Frequency), MF (Medium Frequency), LF (Low Frequency) distortion. Such an approach is interesting only when physical properties of the platform or of the sensor generate spatially-repetitive effects.

If the distortion is purely random, it can be characterised simply by its mean value. Generally the effects will be split between predictable and unpredictable effects. The latter lead generally to unrecoverable errors.

The knowledge of a distortion is not sufficient to absolutely localise a given pixel. The referencing to Earth coordinates has to be ensured. Such a correction can be performed with the help of orbital and attitude information as well as with ground control points and landmarks. Here again, the properties of superimposition of pictures from frame and frame and in absolute value can generate different levels of constraints for the whole system.

. Amplitude quality

The notion of amplitude quality is easier to understand because of the unidimensional properties of the associated parameters.

Generally the first concept to keep in mind is the definition of signal to noise ratio.

The quality of the signal is closely related to this parameter which, in the case of digital data, can be split again into bit quantisation error (bit/pixel, bit error rate) and added signal noise.

A special mention must be made concerning the relationship between S/N and MTF. In image deconvolution a fundamental parameter is the MTF x S/N which defines the theoretical limit of this process.

The field of remote sensing is now so large that quantitative analysis of imagery is necessary in order to obtain the maximum from it.

This pushes the space system as well as the ground preprocessing designers to look more and more carefully at the quality of calibration. That is to say, to determine the law of correspondence between digital transmitted values and physical unit (e.g. scene radiance, temperature, etc.).

Good quality indicators are:

- linearity of the law or at least its regularity,
- inter-channel calibration which guarantees the minimum of distortion for the spectral curve,

- inter-instrument calibration in case of different complementary sensors packed in separate instruments (e.g. Visible push-broom and Infra-red mechanical scanners),

the ultimate step being to determine an absolute law of correspondence, which is probably the most difficult thing to assess.

3. LEVEL OF PRODUCT QUALITY (refer to Figure 3)

In a very general way, a remote sensing satellite system can be split into two domains whose constraints are rather different:

i) the user who is asking for a product of a given quality. This quality is only related to the kind of product the user wants.

ii) The raw instrument picture data and its associated telemetry, whose quality is mainly governed by technological constraints such as power, weight, size of equipment.

- The user quality which corresponds to the preprocessed picture quality only depends on the user's needs, such a quality being split into two or more levels of quality corresponding to different classes of applications. Such a tendency must be limited as much as possible in order to avoid too complex a ground processing organisation.

- The definition of the raw image quality can be arbitrarily chosen, taking into account payload constraints only. This is not the case, however, if direct broadcasting of images is required (other use specification). In this case the raw picture quality will have to match the Low Cost User Station (LOCUS) standard of quality.

The cases of active sensors such as SAR must be treated separately. As these systems do not provide direct readout of a picture, the raw signal must be converted into a picture. The output of such a processor, whether it is on board or on ground, is considered as a pseudo-raw picture to which standard definition of quality can be applied.

The preceding description provides guidelines in order to generally define image quality. In the case of the ESA remote sensing satellite programme, at present under definition, four levels of image quality have been identified:

(a) Raw image, generally for picture utilisation (example: APT, quick look). This product is archived at the station.

(b) System Corrected image (SC). The correction parameters can be pre-defined or calculated in near real time. This product is at present distributed by the Earthnet stations. This kind of correction can be applied in the receiving stations but the raw data have to be preserved, because the system corrections are not always reversible and raw data are essential as a basis for Precision Preprocessing.

(c) Medium Precision Preprocessed (MPP) quality. This level represents the current state of the art. This is the first level of precision preprocessing in which most of the distortions are removed.

(d) High-Precision Preprocessed (HPP) quality. This represents the ultimate goal of PP and, generally speaking, of the whole image processing chain.

In this phase, the errors are effectively removed from the image applying the correction coefficients (application of the calibration, rectification, registration).

The values given to the quality parameter for the Earthnet case are indicated in the associated table (see Figure 4). No quality specifications are given in this document related to the user preprocessed picture or to the payload raw product, as these will have to be defined by the user community and the satellite designers respectively.

4. CONCLUSION

The question of image quality, which was originally a purely instrumental concept, is becoming an important element of the satellite system design. The quality has to be monitored at the level of the satellite design, checkout, inflight control, as well as on-board and ground processing.

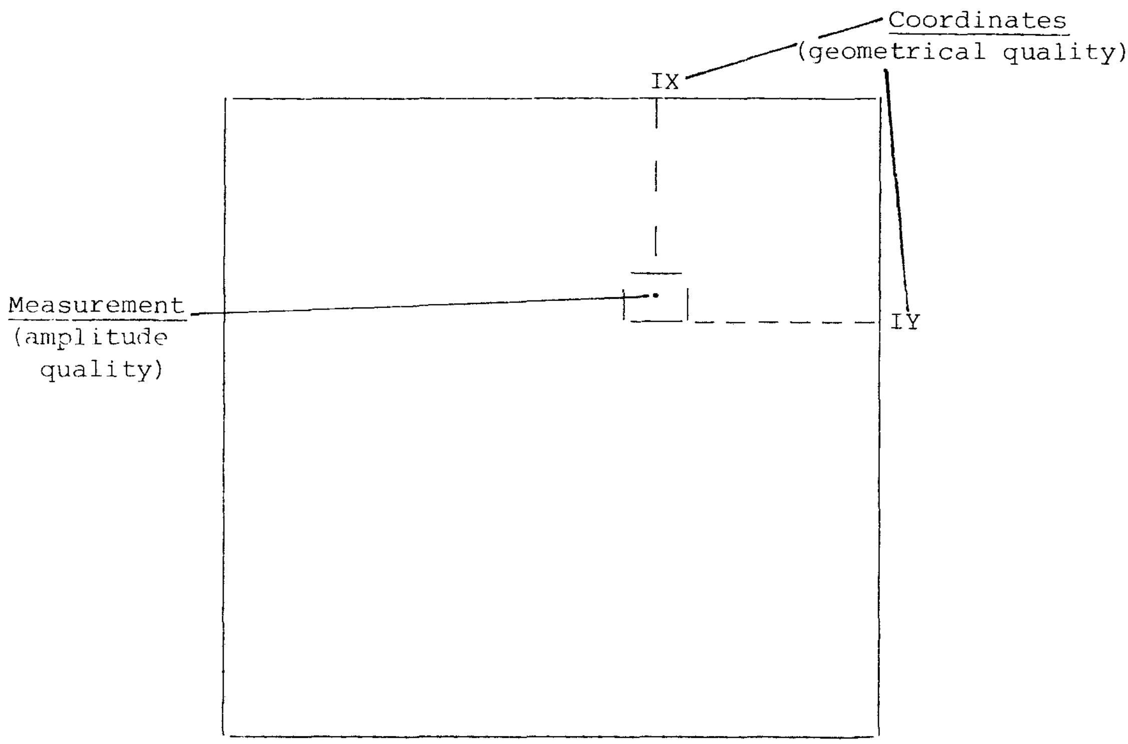
As such, the image quality belongs to one of the basic aspects of the mission definition, and particular attention is being paid to it by ESA in the preparation of the Remote Sensing Satellite Programme.

Level a)	Level b)	Level c)
GEOMETRICAL QUALITY	Picture size definition	1 pixel number/line
		2 number of spectral channels
	Local quality	3 MTF
		4 pixel jitter
		5 registration
	Distortion	6 HF
		7 MF
		8 LF
	Earth referencing	9 frame to frame
		10 absolute
AMPLITUDE QUALITY	S/N	11 quantisation noise
		12 other noise source
	Calibration	13 linearity
		14 intra-instruments
		15 inter-instruments
		16 absolute

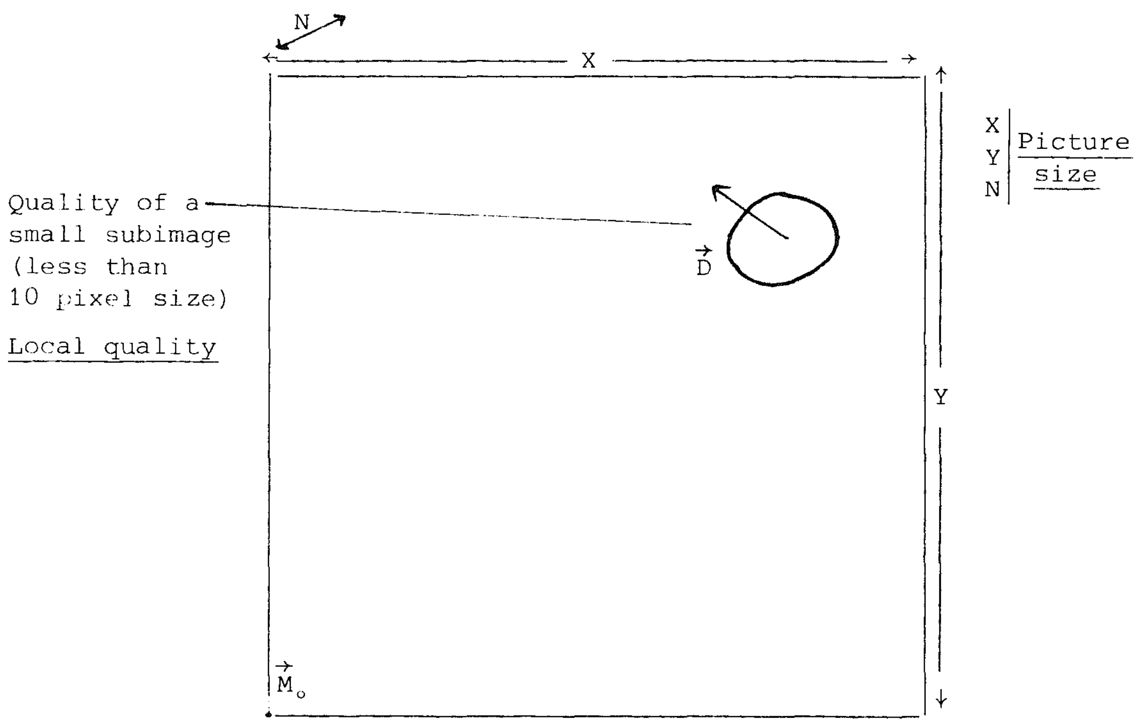
	PAYLOAD X	EARTHNET, LOCUS	
Quality level	Quality of product to be directly distributed (raw product)	Raw product	R
		System Corrected product	SC
	Quality of product after preprocessing (proposed product)	Medium-Precision preprocessed product	MP
		High-precision preprocessed product	HP

Figure 1 - Image quality breakdown structure

Figure 2 - Image quality



Level a)



Difference between reference image and actual image: distortion; positioning of the picture: Earth referencing.

Level b)

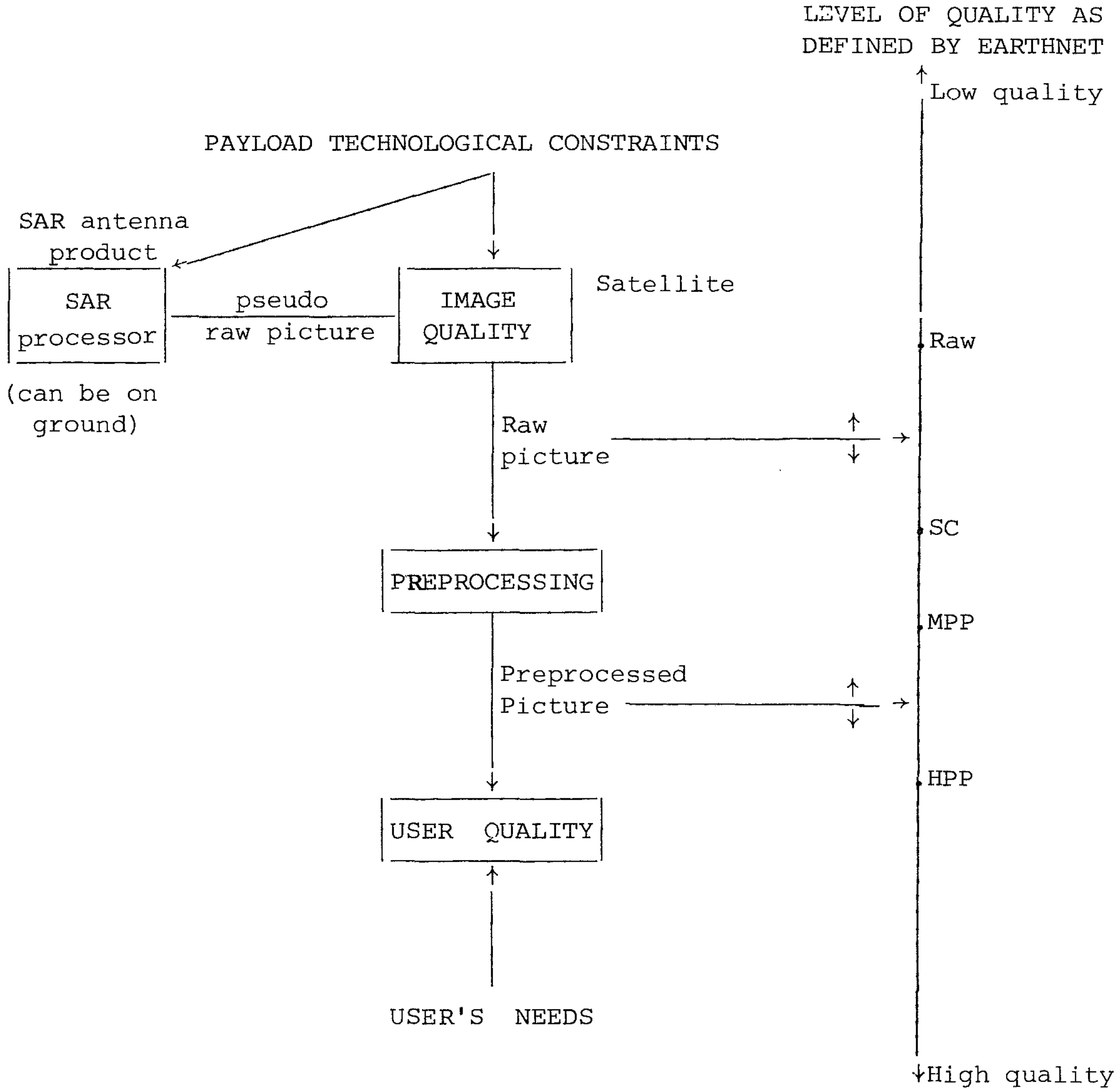


Figure 3 - Level of product quality

*P for Parameter

*P	Raw	SC	MP	HP	
1	4000 / ND	4000 / 4000	4000 / 4000	4000 / 4000	pixels/line lines/picture This parameter is not sensitive. Only the order of magnitude is of interest.
2	6	6	6	6	Number of spectral channels/scene
3	ND	ND	TBD	HP	MTF
4	< 0.5	< 0.5	< 0.5	< 0.5	Rms value of pixel jitter (in pixel value)
5	< 50	< 2	< 1	< 0.5	Maximum pixel distance between 2 channels (in pixel value)
altogether 6, 7, 8	20→ 50 pixels rms	5	1	< 0.5	Distortion in rms (in pixel value)
9	100	5	1	1	Frame to frame remaining error of positioning (in rms pixel value)
10	no limit	10	3.4	1	Error of absolute geographical positioning (in rms pixel value)
11	6 bits	8 bits	8 bits	8 bits	Quantisation accuracy (number of bits/pixel)
12	1 %	1 %	1 %	1 %	N/S in %
13	ND	10 %	1 %	1 %	Linearity of the relationship between image values & energy (in %)
14	10 %	5 %	1 %	1 %	
15	10 %	5 %	1 %	1 %	Accuracy of calibration
16	10 %	< 10 %	5 %	< 5 %	

Figure 4 - Table of quality parameters as used for Earthnet