Prototyping of Interactive Satellite Image Analysis Tools Using a Real-Time Data-Flow Computer

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Abstract. Tools for computer-aided satellite image analysis require interactivity, i.e. the capability to modify some parameters and see instantaneously the result of the processing, for efficient work. Due to the amount of data to process that interactivity can only be achieved by parallel architectures. In this paper, we show how a data-flow computer developed in our laboratory can be used to prototype tools for satellite image analysis. Thanks to its high computational power it was possible to implement two complex algorithms without the loss of real-time interactivity : visualization by means of an anamorphosis and image contrast enhancement. Both tools allow to pan across the image and provide smooth and interactive parameters adjustement. The visualization tool enables the image analyst to preserve global information when zooming on a region. Based on human vision characteristics, the contrast enhancement tool lets the image analyst interactively adjust frequency band gains to optimize target perception.

1 Introduction

Computer-aided analysis of satellite image requires interactive tools allowing human analysts to work efficiently. Because of the huge amount of data embedded in satellite images (typical SPOT image size is 6000×6000 pixels), commercially available low-cost workstations perform poorly when faced with low-level processing of such images (visualization, image enhancement, ...). Nevertheless, the fast increase in workstation computational power should enable them to support attractive satellite image analysis tools in the near future.

In order to investigate which algorithms will be relevant for computer-aided satellite image analysis on these future workstations, we propose to implement various tools on a high performance data-flow computer dedicated to real-time image processing and built in our laboratory, the DFFC (see section 2). This massively parallel computer provides real-time interactive tools, because it is able to take into account parameters modification at 25 Hz.

We focused on two satellite image analysis tools: *visualization* by means of anamorphosis and *local contrast enhancement*. The first tool allows to visualize both local and global information in the image by applying an interactively controled anamorphosis operation. Local constrast enhancement is based on human vision and lets the image analyst interactively adjust frequency band gains to optimize target perception.

2 The Data-Flow Functional Computer

The Data-Flow Functional Computer (DFFC) [5] [4] has been developed at ETCA for on the fly processing of digital video streams. The core of the DFFC is a $8 \times 8 \times 16$ mesh-connected network of low-level custom data-flow processors (6×20 Mbytes/s links, 50 millions operations per second). A fine grain task parallelism is exploited by decomposing an application into a a graph of elementary operators that is mapped on the processors network. Additionally 12 "T800" transputers are used for high-level image processing.

A 16×8 data-flow processors plane of the DFFC provides many input/output links. Each processor of this plane provides a 20 Mbytes/s port that is statically configured as an input or an output. These I/O ports are connected to video boards for cameras and monitors, RAM boards, and to the host workstation (via a VME interface). This latter (SPARC 2) is used to configure the DFFC and to enter parameters (threshold, position, images, ...) by means of a graphic interface during the computation.

A programming language called the Data-Flow Functional Programming (DFFP) language, derived from John Backus' FP [1] has been defined as a high level user interface and a complete software environment [6] has been developed. It includes: a DFFP language compiler which translates a DFFP source file into a Data-Flow Graph (DFG) of operators, a mapper that places and routes a DFG onto the physical network and a graphic editor for manual modification or optimization of the physical DFG. A library of operators and macro-functions has been developed for both types of processors. Users may describe their algorithms in a text form or in a graphic form. They may place and route their data-flow graphs themselves using a graphic editor or let the system do it.

The configuration used for implementing image satellite tools on the DFFC comprises a RAM board for storing images to process (image size is currently 1024×1024 pixels) and a video board for displaying processed images on a monitor (image size is currently 512×512 pixels). In this configuration, whatever algorithm is implemented, the DFFC is able to take parameters modification into account and to refresh the screen at 25 Hz.

3 Satellite Image Analysis Tools

Some basic interactive functions are useful and necessary for computer-aided satellite image analysis : pan, image contrast enhancement, zoom, and switching between the initial and processed image.

The first function enables to detect the different interesting sites in the image. The second and third function lead to fit the image to the image analyst's visual characteristics and help him to detect and to identify the sites. The fourth function is useful to compare the two images (initial and processed) and allows the image analyst to avoid analysis errors due to image processing artifacts.

In this paper, two satellite image analysis tools are presented which combine the functions cited before : *visualization* by means of anamorphosis and *local contrast enhancement.* Each tool features a pan facility, i.e. the user can select the region of the image to process at any time.

Thanks to the computational power of the DFFC an image analyst working with these tools does not have to wait when he adjusts some parameters (the visualization screen is refreshed at 25 Hz). The parameters are entered via a graphic interface running on the DFFC host workstation that was designed taking into account ergonomics.

3.1. Visualization by Means of Anamorphosis

Satellite images are so large (typically SPOT : 6000 $\times$ 6000 pixels) that current screens cannot display them at high resolution. Most often, visualization tools display only a part of the image depending on the zoom factor and the location selected by the user (pan and zoom functionalities). This approach is not completely adequate as it is known that image analysts need both global and local information. In fact they would like to zoom on a region but continue to see its neighborhood on a large scale. For example, an image analyst examining precisely a crossroad, is also interested in seeing a global view of the network to which it belongs (see figure 1).

We propose to apply an anamorphosis operation to obtain such a morphing effect. It can be seen as the projection of a plane onto a curved surface and results in a continuous decrease of the zoom factor when moving away from the screen center.

The following parameters are available to adjust the anamorphosis effect: the location of the visualization window into the image, the zoom factor (from 1 to 5), and the zoomed region size (from a 20 pixels diameter centered disk to the whole screen).

Algorithm Principle. The location of an output image pixel in the input image is obtained with the following mapping function :
$map : (x, y) \rightarrow zoom(\sqrt{(x^2 + y^2)}) * (x, y) + (offsx,\ offsy)$

$zoom(d)$ is a continuous function returning a value between 0 and 1, that depends on the zoom parameters entered by the user. This function is designed to obtain replication of pixels by a decreasing factor when moving away from the center of the vizualisation screen [2]. The position of the visualization window in the input image is defined by $(offsx,\ offsy)$.

Finally the pixels, whose size was increased by replication, are smoothed by applying a convolution with a window of the same size . The process of replicating and averaging is similar to a bilinear interpolation.

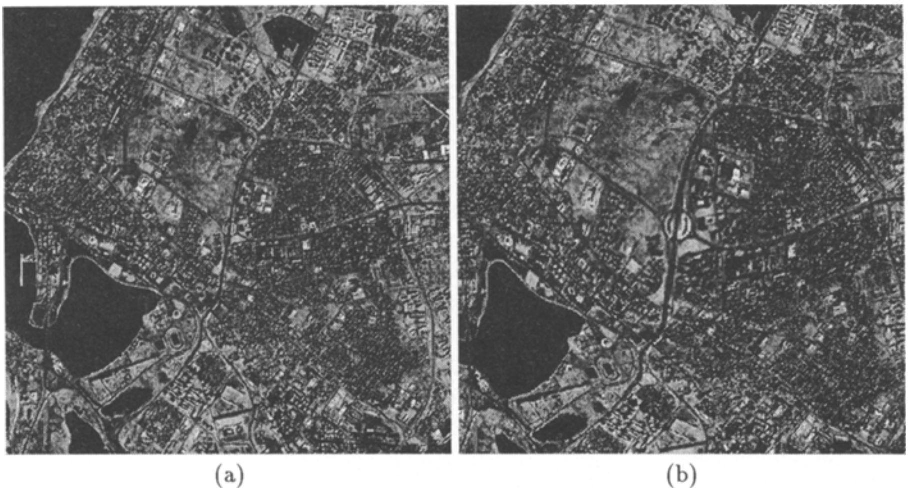

Fig. 1. (a): Original image (b): Anamorphosis with zoom factor 2

Implementation. The implementation uses about 25 % of the DFFC's processors. The algorithm lends itself well to data-flow computation, but requires to compute 16 bits operations (8 bits aren't enough to code the coordinates of pixels) . In fact, its implementation would have been much simpler, if processors were able to compute 16 bits operations.

The host station provides a graphic interface for entering the visualization parameters, and computes the content of two 256 entries look-up tables (*zoom*(), *smooth*()), which are sent to the DFFC. 400 millions of integer operations per second are executed in this application, which prevents from implementing it on a workstation.

3.2. Local Contrast Enhancement

The image contrast enhancement uses a definition of local contrast in complex images. It is based on a spatial and non-linear signal analysis. The original principle has been developped at the IMASSA-CERMA (a french military institute for spatial health) from studies of the human vision [3]. This definition arises from the following visual system properties : logarithmic sensitivity to the luminance and spatial frequency sensitivity.

Algorithm Principle. The wavelet transform provides a multiscale analysis that splits the signal into spatial frequency bands while maintaining the information of localization attached to each component. The local contrast achieves a logarithmic form of this image analysis. As a result of local contrast analysis, such a quantification, modeling visual analysis, leads to determine whether information can be visually perceived, otherwise the information can be fitted to operator's visual characteristics as well as to the task he is involved in.

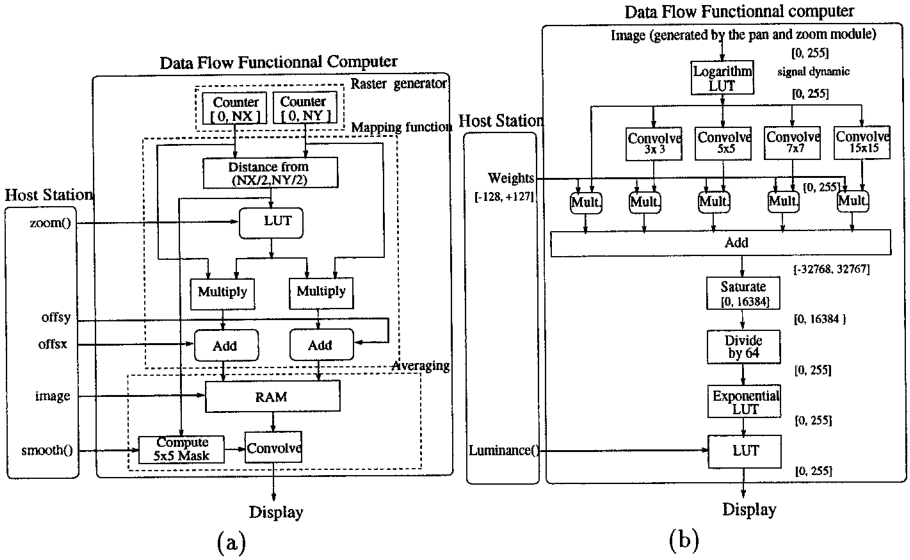

Fig. 2. (a): Anamorphosis Algorithm (b): Local Contrast Enhancement Algorithm

For the interactive satellite image enhancement, the user can improve selectively the contrast in function of the target size (roads, missile battery, transmission building, ...). For accurate perception of details, it is necessary to amplify specifically high spatial frequencies.

Local contrast enhancement is achieved by applying the following operations to the image. After a logarithmic transformation, a wavelet decomposition is made to obtain images associated with a set of frequency bands. Then a linear combination of the frequency band images, whose coefficients are interactively adjusted by the user, is computed. Finally an exponential transformation is applied, followed by a global luminance and contrast transformation.

Implementation. In our implementation, wavelet decomposition is computed by convolutions rather than by pyramidal wavelet transform. This latter requires less regular data handling (sampling, interpolation) and would be difficult to implement on the DFFC. The wavelets base used are "DOGs" (Differences of Gaussians) functions with 4 different sizes. Therefore it was possible, in order to simplify implementation (only positive weights), to convolve with 4 gaussian kernels of size 3×3, 5×5, 7×7 and 15×15 and to subtract resulting low-pass filtered images at the linear combination step.

The image analyst can adjust the following parameters to control the local contrast enhancement : the gains applied to 4 spatial frequency bands, and the global luminance and contrast. This kind of algorithm particularly benefits from the implementation on the DFFC, as interactive processing makes easier and faster the adjustment of the set of parameters.

The convolutions represent a major part of the computations and result in a 45 % use of the DFFC's processors. Associated with the pan facility, the local contrast enhancement tool uses 70 % of the processors. It requires the impressive number of 3 billions of integer operations per second to refresh a 512 × 512 pixels screen at 25 Hz.

4 Conclusion and Future Work

In this paper, we proposed to use a data-flow architecture dedicated to real-time processing in order to implement various satellite image analysis tools. First, a visualization by means of anamorphosis tool was presented. The anamorphosis operation preserves global information while zooming on a region in the image. Second, we described a local contrast enhancement tool based on human vision. Thanks to the high computational power of the DFFC, algorithms parameters are controled interactively at 25 Hz.

Future work will consist in letting users work with our satellite image analysis tools in order to extract some statistics on how they adjust parameters of the algorithms. This feedback could enable us to propose parameters presets, and further to automatically adapt parameters depending on statistical characteristics of the image and on the target of the analysis. We will study the relevance of the different parameters in order to simplify and adapt the algorithms.

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