Grid Computing-based Satellite Image Processing for Fire Prevention

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Abstract **– This paper presents the processing stages of a satellite image processed in a grid network with the aim of fire prevention. The steps followed by a satellite image in order to realize the proposed purpose are: image pre-processing, image segmentation, image segments distribution into the grid network, image segments processing and image recomposing validation and analysis. All presented image processing aspects will be implemented in a Romanian research project entitled MEDIOGRID.**

1. INTRODUCTION

Fire is an event part of natural hazard, resulted both as a natural event as well as from human activity. There are some remotely fire signals like heat, smoke and charring. The satellites are also monitoring the susceptibility of vegetation to fire at the landscape level.

Related the heat were developed some algorithms like earlier Matson-Dozier algorithm[1], which estimates sub-pixel active fire (i.e., combustion zone). There are some problems related fire determination like background surface temperature, uncertainty about the emissivity of different surfaces. More recent algorithms [2], [3] include contextual criteria which essentially perform a task of locally-adaptive thermal edge detection.

For smoke detection associated with active fire were elaborated some other algorithms [4], [5].

Charring was also in researchers' attention but post char/scar signal is considered more accurate for assessment of area burned [6]. Currently, there are no community-consensus algorithms for burned area detection and mapping. Some of the algorithms rely on static interpretation of composite imagery and others track changes in time series of imagery. Both types of algorithm use vegetation indices and thermal data [7], [8], [9].

Vegetation susceptibility to fire is important both for Europe and Africa. In Europe essential ingredients for monitoring are vegetation phenology and water stress, and land surface temperature.

Fire detection parameters relevant for studies are: albedo/reflectance, LST and emissivity, fractional cover with clouds, soil moisture, canopy structure, fire duration aerosols and fuel loading.

Fire detection was realized by using different satellite meteorological sensors. The most used long time, long distance sensor is AVHRR (Advanced Very High Resolution) from the board of NOAA orbital polar satellites.

In the first section of the article are presented introductory notions about fire prevention.

The section 2 addresses the background for the satellites used in images acquiring and the sensors they use.

The satellite images formats and characteristics are detailed in section 3.

Section 4 contains the used fire algorithms theory.

In section 5 are described the needed images processing steps like pre-processing, satellite image segmentation and distribution into the grid network, data processing in grid system and sub-areas information analysis and global interpolation, validation and results analysis.

A contextual algorithm for fire prevention in Romania is presented in section 6.

The last section summarises the conclusions.

2. BACKGROUND

The images captured by geostationary satellites are useful in short term meteorological prediction as well in climate or landscape ones. Satellite data describing clouds and land surface characteristics are also increasingly useful in weather and climate prediction. This reflects the growing recognition of the important role that the land biosphere plays in determining weather conditions and in the interactions with the atmosphere that result in seasonal to inter-annual climate variations. A single geostationary satellite cannot provide global imaging. Nowadays there are 21 geostationary satellites placed on 3 operational spares, 6 orbital planes, 55 degree inclinations, 12 hour orbits.

Space exploration instruments –sensors- differ from one satellite to another. For instance GOME-2 was developed for METOP 1-3 and is in the range of 240 – 790 nm, with a spectral resolution of 0.2 and 0.33nm, and a pixel resolution of 80x40 km or 40x40 km. Another instrument is HIRS/2, 3, 4 for NOAA satellites and has 19 channels in the range of 3.8 – 15.5 μm and 1 channel in visible spectrum (VIS). The European spatial mission Meteosat (MSG) is equipped with the principal sensor, the Spinning Enhanced Visible and InfraRed Imager (SEVIRI). The spectral, radiometric and spatial characteristics of SEVIRI should thus enable observations of land surface parameters and processes, in addition to those of the atmosphere. Coupled with frequent imaging, these observing capabilities give access to information currently unavailable from polar orbiting satellites. Geostationary satellites allow measurements at much shorter time intervals, 15 minutes in the case of MSG.

The 12 SEVIRI channels are distributed throughout the short and long wave parts of the electromagnetic spectrum. This feature in conjunction with the frequent repeat cycle, provides the basis for improved and new products to be used for applications such as Numerical Weather Prediction (NWP) and climate monitoring. The image repeat cycle is 15 minutes with a sampling resolution at the sub-satellite point (SSP) of 3x3 km for all channels except the VIS high resolution band (HRV) which has a 1x1 km nadir resolution. The ground resolution and imaging frequency have increased by a factor two with respect to Meteosat, and the number of channels has been multiplied by four.

Satellite based lightning detection and location methods are not operationally implemented, but a few platforms are in work now since the middle of the 1990s. These include the NASA development of optical lightning sensor arrays (OTD, LIS) and the multi-sensor (RF and optical) satellite FORTE launched by the Los Alamos National Laboratory.

For fire detection were used different meteorological satellite sensors. The most used one for landscape large fires monitoring is Advanced Very High Resolution (AVHRR) of polar orbital NOAA (National Oceanic and Atmospheric Administration) satellites [13], [15], [18], [20], [24].

Visible spectral bands can detect fire smoke. The thermic ones can detect active fires as well as so-called “hot areas”.

All spectral channels provide fire information but only multi-spectral processing offers needed information for event recognition.

3. SATELLITE IMAGES CHARACTERISTICS AND FORMATS

There are several physical parameters which influence the radiance: cloud top pressure, cloud optical thickness, cloud geometrical thickness/ the vertical structure of the clouds, possible stratification of clouds, temperature / pressure profile, surface albedo (spectral and total), effective radius of the cloud particles [10].

The OpenMTP format is a new format developed for the METEOSAT Transition Programme (MTP). It represents a progression from the IBM-compatible 'IBMMOP' format used by ESOC during the preceding Meteosat Operational Programme (MOP) which ran until November 1995. The image data will actually be represented in numerical counts coded on 10 bits. All the information that is necessary to transform this count into radiance will be available in the file header and trailer.

The product consists of a variable number of logical records of variable length. This structure contains three distinct components detailed in Table 1.

Record	Specs	Dimension (bytes)
1	ASCII Header	1345
2	Binary Header	144515 (channels except VIS)
		192999 (VIS composite)
3..N	Image Lines	Number of pixels + 32 bytes / line (trailer)

Table 1. Satellite images structures

Initially there were used only types 2 and 3..N records format (Unix platform compatible) but newly, it was introduced record 1 type for some other platforms compatibility (see Table 1).

For full disk imagery (the most common format), this gives the following sizes:

- IR (infra-red) 6.475.860 bytes
- WV (water vapor) 6.475.860 bytes
- VIS-N visible-north) 12.725.860 bytes
- VIS-S (visible-south) 12.725.860 bytes
- VIS Composite 25.354.344 bytes

These dimensions are not huge for nowadays computers capacities but they are captured ones at each 15 minutes. This implies the need of their segmentation and computing in a grid network.

Aside OpenMTP format (base format) there are some other used ones like level 1.b LAC/ HRPT, level 1.5 MSG formats. The level 1.5 images are formatted, disseminated and archived in the U-MARF and are some of the main Meteosat productions. This data level corresponds to the acquired image data, corrected for all radiometric and geometric effects. The images are geo-located by using a standardised projection, with constituent pixels calibrated [11].

The original HRPT architecture has the header and scanned line at the same size, meaning 10090 bytes.

NOAA Level 1b format consists in a set of records with the 14800 bytes size. The header of the file has 122 bytes. Next record represents the line header followed by the scanned line satellite image data.

Level 1.5 data is derived from the Level 1.0 data that is acquired by the MSG satellite and received by EUMETSAT’s ground segment. EUMETSAT corrects in real-time each received level 1.0 image for all radiometric and geometric effects and geo-locates it using a standardized projection. The resulting level 1.5 image consists of Earth-located, calibrated and radiance linear information that is suitable for the derivation of meteorological products and other further meteorological processing. An HRUS (High-Rate User Station), receiving the high-rate data disseminated at 1 Mbit/s, is capable of receiving disseminated level 1.5 data in near real-time and with full spatial&temporal resolution.

The Level 1.5 pixel binary representation is 10-bit (8-bit for LRUS - Low-Rate User Station - received data), corresponding to linear and equalised image information (corrected for differences in response between the contributing detectors). For each scan of the earth disc by the MSG satellite, image data for 12 different spectral channels is produced in nominal operations.

Record structure depends on its spectral type. One type of record structure is designed to hold the data of the nominal line-size of 3712 pixels (i.e. the 11 types of visible (VIS) / infra-red (IR) data), and the other to hold the greater line-size of 5568 pixels (i.e. that of the high-resolution visible (HRV) channel). The channel-ordering of the image data constituting one scan line is as follows: VIS 0.6, VIS 0.8, NIR 1.6 (Near-Infra-Red), IR 3.9, IR 6.2 (WV), IR 7.3 (WV), IR 8.7, IR 9.7 (Ozone), IR 10.8, IR 12.0, IR 13.4 (CO2), HRV.

4. ALGORITHMS FOR FIRE PREVENTION

Most fire prevention algorithms might be classified in three categories:

1. algorithms which use a threshold value applied to some physical parameters obtained from numerical data calibration registered in spectral channel 3;
2. algorithms which use many threshold values for many spectral channels;
3. contextual algorithms based on pixel comparison between the pixel characterized as being of fire potential with those on its neighborhood with thermic properties.

In order to extend detection algorithms utility that use many spectral channels, were proposed contextual algorithms [23]. This implies the following two essential procedures:

- initial setting of threshold values for the fire pixel identification
- threshold values adapting in order to chose the pixels of real fire unless those of fire potential [26].

The steps included in the first procedure are similar with the techniques of the algorithms for multiple spectral channels.

In the second procedure is computed the average and standard deviation of the variables that define threshold values taking into consideration the pixels of no fire potential (free pixels) situated near a pixel of fire potential. The pixel window size for which is done the computing is chosen in an ad-hoc manner, varying from 3x3 pixels to 21x21 pixels [16] until the free pixels number reaches a specified value (generally 25%). After the obtaining of these statistics the threshold values are redefined in order to confirm a fire. Giglio et al [17] proposed different threshold values to identify possible live fires and confirm the active real ones (fig. 1).

For regions (sub-areas) there is the advantage of threshold values setting relative to the seasonal variation of the investigated scene properties.

5. SATELLITE IMAGES PROCESSING

As we are presented in the section 3, the satellite files received contains statistical parameters and satellite images, and the size of these files is huge.

In order to obtain, in real time, meteorological or natural disaster predictions (fires, snow falls, floods) is recommended data processing in a grid system.

Satellite images are following the next processing steps:

- pre-processing (primarily data processing)
- satellite image segmentation and distribution into the grid network
- data processing in grid system and sub-areas information analysis

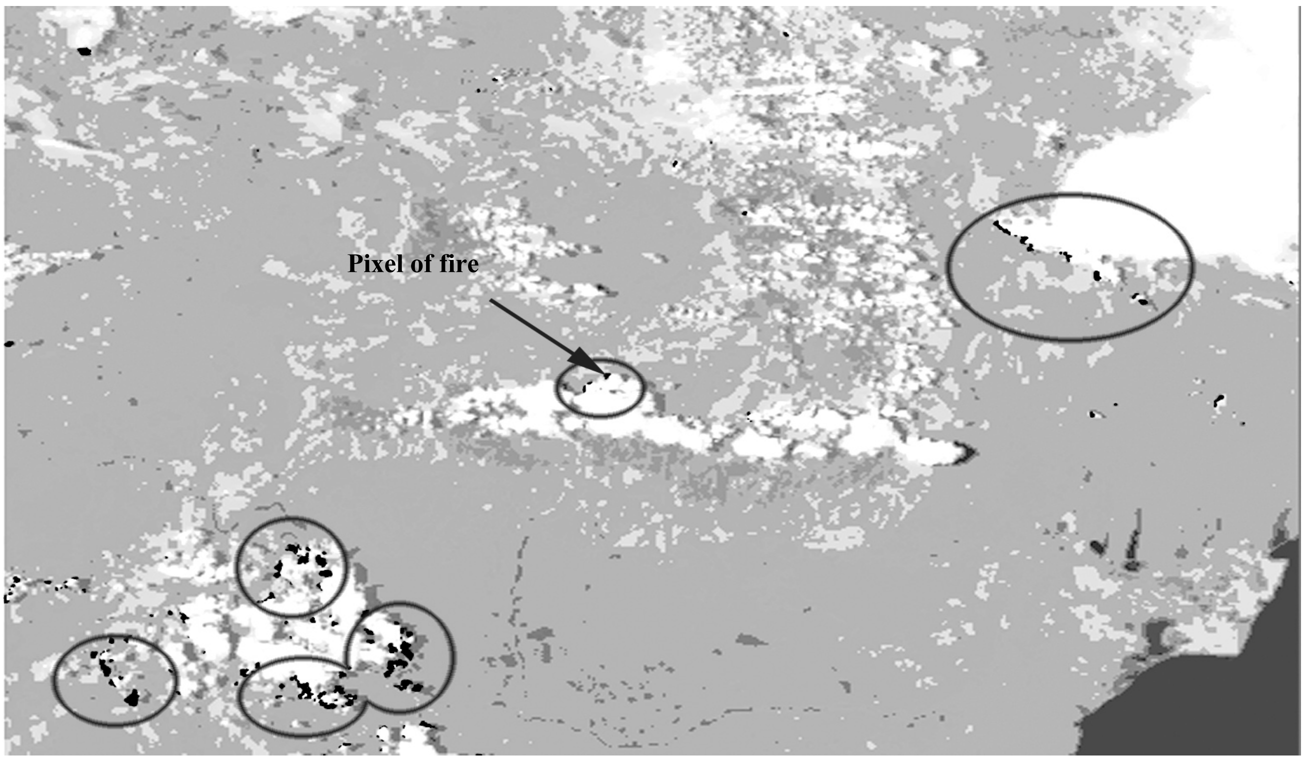

Fig.1. Romanian areas with fire potential identification on 8.07.2000 by using the satellite image NOAA 14, 16:47 TL.

- global interpolation, validation and results analysis.

5.1. Satellite images pre-processing

NOOA satellite images (the tested ones) pre-processing within fire prevention consists in:

1. decode the satellite numerical data files NOAA/AVHRR
2. satellite data qualitative verification
3. correction of geometrical distortion
4. satellite images calibration

5.1.1. Decode the satellite numerical data files NOAA/AVHRR

An important characteristic of the NOOA/AVHRR sensor is its spatial resolution (~ 1 km). In order to take advantage of this characteristic, it can be used only the data type registered with the AVHRR/HRPT, level 1b LAC format (LAC/HRPT). The spectral information is stored in a 10 bits resolution. The data contains 5 values, one for each channel. Each channel has 2048 points in a scan line so, for all 5 channels there are 10240 records.

Some of these format types are encoded some others don't, but they can be registered on 10 consecutive bits or 16 bits. This depends on the acquisition system and storing data program.

By using Level 1b format (and not HRPT) there is the advantage of a qualitative checking and of an extra calibration and localization (latitude and longitude) information added.

5.1.2. Satellite data qualitative verification

Sometimes satellite images lose information during acquisition a part of their scanned lines, in this regard being recommended a verification, especially for fire prevention where the consistent information is at the pixel or sub-pixel level.

5.1.3.Correction of geometrical distortion

Generally, numerical data contains geometrical errors. These errors can be corrected by using two methods:

- orbital parameters updating
- by the mean of GCPs (Geographic Correction Point)

Orbital parameters updating implies knowing satellite platform characteristics as well as sensor's internal distortions.

The NOAA images spatial coverage is huge and this because of the system which consists in a mirror with a 360^0 rotation. The angular observations of extreme areas are very oblique. These distortions can be corrected by using orbital models.

Many GCPs should be used in order to correct an image.

5.1.4. Satellite images calibration

One of the pre-processing activity is calibration. The calibration coefficients are derived in real-time based on the black body information of each detector, accounting for the contribution of the front optics. There are two elements to the calibration process: the Relative Calibration and the Absolute Calibration, both processes are applied to the IR and WV channels. The relative calibration process uses data from the 2 on-board black bodies to compensate for small changes in absolute calibration. The output of the process is adjustment factors FIR (IR Factor) and FWV (WV Factor) which are used to scale the absolute calibration coefficients IR and WV.

5.2. Satellite images segmentation

Segmentation is important for data processing in the grid network. The segmentation and the distribution into the grid network processes can be realized in one of the following modes:

- automated (by the computer)
- supervised (by the user)

The segmentation can be done also in one or many processing iterations.

We distinguished 3 cases for satellite data segmentation:

- spatial
- temporal
- features based

Segmentation process extracts a set of statistical parameters characterizing the scenes (i.e. areas of the earth surface with nearly homogeneous radiation behaviour and clouds at different height levels) from the available spectral data (IR, VIS, WV) of an image. This is done for each segment of the processing sub-area. The applied method is called Multi-Dimensional Histogram Analysis (MDHA).

Depending on the spectral data available for a segmented image, the following four modes of the image data processing can be distinguished:

- scenes data extraction from IR image data only
- scenes data extraction from IR and VIS image data
- scenes data extraction from IR and WV image data
- scenes data extraction from IR, VIS and WV image data.

Based on segmentation criteria we distinguished the following image segmentation types:

- spatial segmentation like: administrative units, geographical regions, countries, districts; sub-areas (disjunctive or non-disjunctive regions)
- temporal segmentation like time counts (integral set of layers or only some interest layers, based on application type picked for given moments of time)
- features based segmentation like graphical aspects oriented (e.g. colours, shapes or contours detected in an image), layers (spectral bands)

5.3. Data processing in grid system and sub-areas information analysis

The obtained segments are distributed in the grid network.

There are few steps followed by an image after this distribution:

- useless information masking (clouds masking and atmospheric corrections)
- semantic information extraction

5.3.1. Useless information masking

5.3.1.1. Cloud Masking

For land biosphere applications, the part of the signal originating in the atmosphere represents an undesirable perturbation. The most significant source is clouds, and cloud identification and masking are therefore of crucial importance to obtaining high quality land surface products. Of special interest is partial contamination of the signal, due to small (sub-pixel) or translucent clouds. In these cases, the contamination may be more easily confused with the surface signal and thus erroneously interpreted as a different level of the latter. Thus, a high quality cloud detection and masking procedure is a key to successful applications to land biosphere. Such a procedure should make effective use of all information from the various spectral bands. The cloud masking algorithms should be optimized through comparisons with masks derived from other satellite data and should be subject to regular quality control procedures.

5.3.1.2. Atmospheric corrections

Atmospheric information for times coinciding with sensor data acquisition must be readily available outside the meteorological community to enable the derivation of biophysical variable products. Of particular importance are vertical profiles of atmospheric water content, pressure and temperature.

5.3.2. Semantic information extraction

Consists in the following processing steps:

- pre-processing in visible and near-infrared (1 and 2 channels).
- pre-processing of spectral information provided by channel 3 (medium infra-red)
- pre-processing of thermic bands in infrared (4 and 5 channels)

5.3.2.1. Pre-processing in visible and near-infrared

Includes the next stages:

- calibration coefficients calculus for the "d" day after launch
- digital data conversion into radiance
- radiance conversion into apparent reflectance

5.3.2.2. Pre-processing of spectral information provided by channel 3 (medium infra-red)

The AVHRR 3 channel (3.75 µm) is a mixture of reflected solar energy and thermic emission. Because the spectral band is overlapped somehow over absorption band (sensible at water and vegetation on the soil) the determination of reflective component of this channel is considered useful for stress analysis of the vegetation and fire affected surfaces.

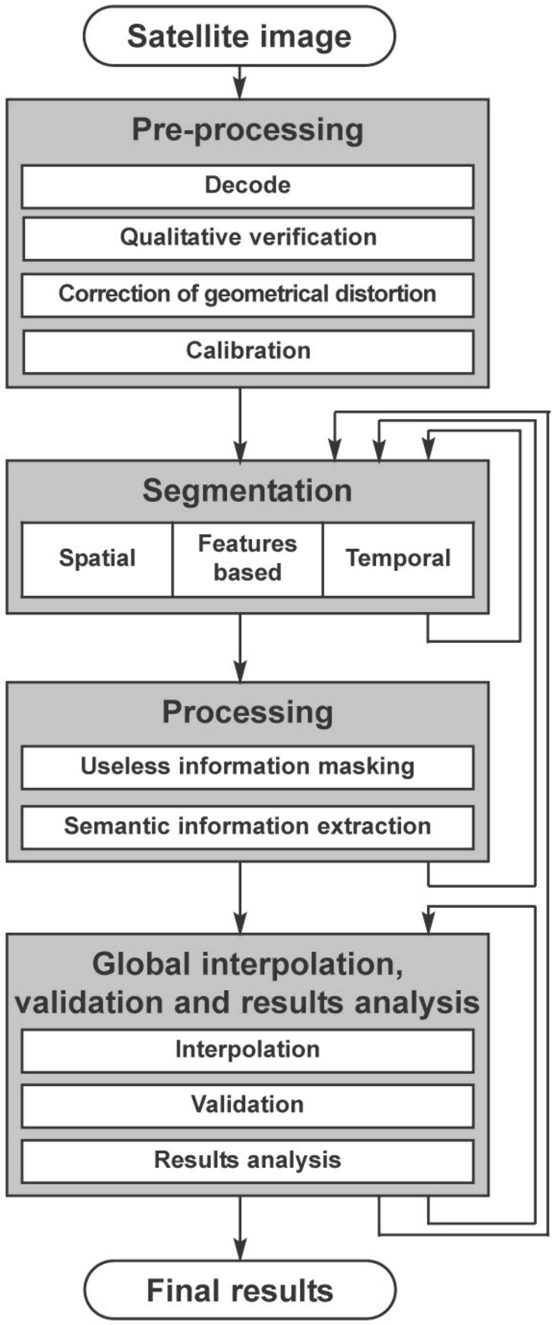

Fig. 2 Satellite images processing steps

5.3.2.3. Pre-processing of thermic bands in infrared

The pre-processing consists of:

- Digital numeric data (DN) conversion into radiance (L)
- Radiance (L) conversion into lighting temperature (T*)

5.4. Global interpolation, validation and results analysis

After segments processing into the grid network the image is recomposed and globally analyzed. Image re-composition is done by interpolation based on the control points (values obtained after grid processing) by the mean of used algorithms (Bezier, triangulation, etc.).

Qualitative image checking is visually performed and is useful for data validation and as a step for interpretation.

Based on this re-composed image and on critical threshold of the studied event is determined the landscape danger (natural disasters).

All detailed processing steps are presented in figure 2.

6. CONTEXTUAL ALGORITHM FOR WOOD FIRE DETECTION IN ROMANIA

In order to establish an active fire detection methodology for Romania there were tested the following algorithms : IGBP-DIS [25], GIGLIO [17] and ESA (European Space Agency; [14]).

Between these algorithms is remarked IGBP. The detection thresholds used in this algorithm are bigger in comparison with the others (about 8K for lighting temperatures for spectral channel 3).

The main stages of IGBP model for active fire detection are:

- potential fire areas isolation
- hot areas exclusion
- opaque clouds exclusion
- transparent clouds exclusion
- residual cloud borders exclusion
- water mirror effect exclusion
- statistics in the neighbourhood pixels of fire potential (3x3 to 15x15 window size)

Statistical calculus are resumed at lighting temperatures comparison for channel 3 (T_3) between pixels of fire potential and the obtained sum between the lighting temperatures average for the same channel and the standard deviation of them corresponding to the pixels located in the fire potential pixel neighbourhood.

The presented algorithm is going to be parallelised and applied into the grid network during the implementation of MEDIOGRID project.

7. CONCLUSION

This paper presents the procedures satellite images follow in and out of a grid processing in order to prevent natural disasters especially woods' fire.

Generally, fire disasters prevention algorithms are validated based on the number of located and un-located fire disaster. If one of the following steps isn't done: geometrical distortion, images qualitative checking or calibration, the possible errors number increases. Decoding image formats is another essential process in satellite data reading.

The specifications of the presented sensors appear very adequate to study the thermal signal of larger fires.

The new dimension satellites provide measurements over Europe and Africa every 15 minutes in a broad range of the electromagnetic spectrum. This allows the diurnal cycle to be properly resolved and provides more opportunities for imaging the Earth's surface through gaps in the cloud, thus yielding more complete surface products.

All presented image processing aspects will be implemented in a Romanian research project entitled MEDIOGRID.

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