FOREST FIRE DETECTION WITH SATELLITES FOR FIRE CONTROL

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KEY WORDS: Forestry, Automation, Temperature, Real-time, Thermal, Wild-fire, AVHRR

ABSTRACT

A prototype software has been developed for automatic detection of forest fires using NOAA AVHRR (Advanced Very High Resolution Radiometer) data. Fire detection is based on mid-infrared data (band 3 of AVHRR, 3.5 μm). Bands 2 (near infrared) and 4 (thermal infrared) are also used in the fire detection algorithm.

In an experiment in 1994, all six detected fires that were in areas where verification was possible were real fires. In 1995, at least 17 out of 19 verified cases were high temperature targets. Three cases were industrial sites that can be excluded based on their known location. This shows that satellite based detection of forest fires has potential for fire control purposes provided that the supply of mid-infrared satellite data in day time is frequent.

1 INTRODUCTION

Satellite based wild fire detection has proven a viable tool in collecting statistical information on the emission of greenhouse gases in the past (see e.g. Setzer and Pereira, 1991). The characteristics of the NOAA series of meteorological satellites make it possible also to collect near real-time information in support of fire control activities (Flannigan and Vonder Haar, 1986).

Forest fires is one of the most frequent type of natural hazards in Finland. The Finnish Ministry of the Interior, VTT Automation, and the Finnish Meteorological Institute started a project to develop a prototype system for forest fire detection as a Finnish initiative in the context of the International Decade for Natural Disaster Reduction (IDNDR) as declared by the United Nations. The system is based on meteorological satellite data. The real-time fire detection is done for fire control purposes.

Many of the NOAA AVHRR -based fire detection studies concentrate on tropical areas (e.g. Kennedy *et al* 1994). In tropical areas, surfaces with no vegetation such as deserts or mountains usually warm so much in the afternoon hours that the band-3 signal in AVHRR becomes saturated. In the *Boreal* forest zone this phenomenon does not occur and therefore there is one possible error source less than in the tropical areas or in the Mediterranean basin (e.g. Illera *et al* 1994 and Gonzalez Alonso & Casanova Roque 1994).

Most fire detection algorithms make use of data in bands 3 and 4 of the AVHRR sensor. One fire detection algorithm – based on the algorithm published by Kaufman *et al* (1990) – is proposed by Kennedy *et al* (1994): (*i*) $Bt_3 \geq 320$ K, (*ii*) Bt_3 minus $Bt_4 \geq 15$ K, (*iii*) $Bt_4 \geq 295$ K, and (*iv*) ToA reflectance in band $2 \leq 16$ per cent where Bt_i = brightness temperature in band i and ToA = Top of the atmosphere.

2 SATELLITE DATA SUPPLY

NOAA AVHRR data are received by the receiving station operated by the Finnish Meteorological Institute. Of the five wavelength bands present in the AVHRR sensor, three are used in the fire detection system: band 2 (reflected infrared), band 3 (middle infrared), and band 4 (thermal infrared). The receiving station system extracts a sub-scene of 1024 lines by 1024 pixels from each satellite pass, which can be over 5000 lines by 2048 columns. The sub-scene is extracted in such a way that its centre point coincides with the centre of the defined monitoring area.

The extracted (3-band) sub-scene – together with the associated timing and calibration data – is then automatically sent to the computer where the fire detection system runs via a digital network. The fire detection system scans the directory of incoming image data at regular intervals. Every time it notices a new data set in this directory it starts a processing chain to find fires in the data set.

3 TRANSFORMATION OF NOAA AVHRR DATA INTO FIRE INFORMATION

An overview of the derivation of fire information from NOAA AVHRR data is shown in figure 1.

3.1 Pre-Processing of NOAA AVHRR Data

Location of a detected fire is of utmost importance if the fires are detected for fire control activities. The NOAA AVHRR data are therefore geo-coded before the fire detection. Geo-coding is based on predicted orbit data.

Orbit telexes are received for satellites used once per day (usually two to three days before the day of validity of the telex). The orbit telexes are archived in the fire detection system. Each time a new data set is fed into the system, the most recent orbit telex of the satellite in question is used.

Many times the image reception from satellites is not perfect but the signal deteriorates during the tracking of the satellite so that the data stream consists of random numbers instead of data measured by the AVHRR sensor. These reception errors are usually in blocks of one to ten consecutive scan lines. The fire detection system checks the incoming data set (by computing line averages for all three spectral bands) and marks all lines where at least one of the three line averages deviates from the scene average by more than a pre-selected threshold. The detected reception-error lines are then excluded from further processing.

Interpolation grids are used in image geo-coding. The geo-locations for a grid (approximately every 30th line and every 30th column) are computed based on the orbital data and

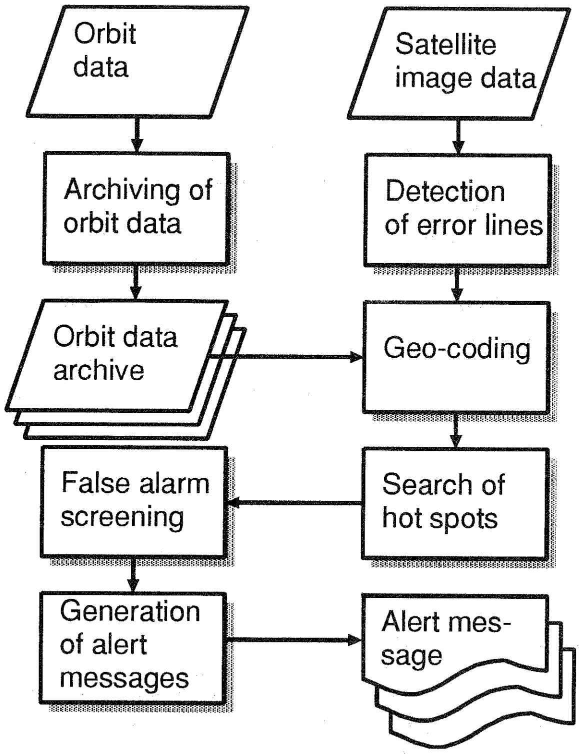

Figure 1: Tasks in fire detection.

the timing information extracted from the image data. This interpolation grid is then inverted and used when the image data are resampled to a regular pixel grid in the selected map projection (Gauss-Krüger).

Resampling is a critical step in image processing if the aim of the system is to detect small active fires. Usually a fire affects only one pixel in a NOAA image. If bi-linear interpolation is used in resampling, most of the one-pixel fire signals are rendered undetectable as a consequence of the averaging introduced. On the other hand, if cubic convolution is used, numerous false alarms are generated especially along sharp edges in connection of boundaries between clouds and cloud shadows. This is due to the edge enhancement that cubic-convolution resampling produces. The most suitable standard resampling technique for fire detection is the nearest neighbour resampling. If the pixel grid of the geo-coded image is dense enough (the inter-pixel distance of the AVHRR sensor at nadir is approximately 0.8 km), no fire signals are lost in the resampling and no false alarms are generated either.

3.2 Fire Detection Algorithm

As in many other systems, the detection of small fires is based on the use of band-3 data (wavelength 3.5 μm). All pixels that have a digital number less[1] than a pre-determined threshold are considered to be potential fire pixels. These pixels are searched in the image and connected fire pixels are grouped together to form fire patches or "hot spots".

In addition to the spectral features used widely in fire detection, the fire detection system takes into account the imaging geometry. The imaging geometry is represented by the deviation angle. The deviation angle α is the angle between the direction of reflected sun light and the line of sight from target to the sensor (figure 2). The deviation angle is computed:

$$\alpha = arc\ cos(\frac{S \cdot R}{|S||R|}) \tag{1}$$

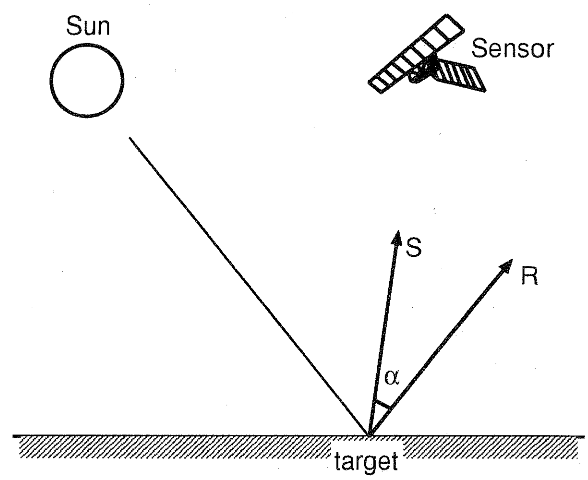

Figure 2: The deviation angle between the vectors R (reflected sun light) and S (target to sensor).

A detected hot spot is considered to be a real fire only if it fulfils all of the following criteria:

1. the deviation angle must be greater than a pre-determined threshold,
2. the band-2 average of the hot spot must be smaller than a pre-determined threshold,
3. the band-4 average of the hot spot must be smaller than a pre-determined threshold,
4. the hot spot must be further than a pre-determined threshold away from the borders of the image swath,
5. the number of pixels in the hot spot must be smaller than a pre-determined threshold.

As in (Pereira and Setzer, 1993), the original digital numbers are used as such and are not converted into temperature units. Conversion to temperature units would make the thresholds directly comparable with those used in other systems. It would not make the system more general because the thresholds must be adapted when moving from one ecosystem to another (Kennedy *et al* 1994).

Despite the fact that the data are not converted to temperature units, the fire detection algorithm resembles the algorithm described by (Kennedy *et al* 1994). The search of hot spots based on band-3 data corresponds to criterion *i*. Criterion 3 corresponds to criterion *iii* and criterion 2 to criterion *iv*. The criterion *ii* is always fulfilled in hot spots detected in the *Boreal* forest zone where extremely hot natural targets are missing. The criteria of geometric nature (criteria 1, 4, and 5) in the list above are such elements in the algorithm that do not have counterparts in the algorithm described by (Kennedy *et al* 1994).

[1] The digital-number scale in bands 3, 4, and 5 of the AVHRR sensor is reversed so that high radiant power corresponds to low digital numbers and low radiant power to high digital numbers. That is why low digital numbers are sought for in fire detection, not high.

4 FIRE MONITORING EXPERIMENTS WITH THE SYSTEM

So far the prototype of the fire detection system has been tested and demonstrated in three phases. Only two NOAA satellites were used in each experiment.

4.1 Test Phase in Summer 1993

In summer 1993, the system operated from 1 June to 20 August. More than 330 images were analyzed by the system (Häme and Rauste 1995). Of these 330 images, the system reported 66 images as containing a possible fire. Because the automatic screening of false alarms was not in use in 1993, these 66 images were inspected visually. In four cases, no other reason but a high-temperature target on the ground could be identified for the hot spot. Two of the four detected fires were outside Finland and therefore practically impossible to verify. One of the Finnish fires was verified as a real forest fire, where the total area burned was 30 ha. The NOAA scene where the fire was detected was received 1-2 hours after the start of the fire.

Another test was carried out using a limited set of NOAA images acquired over Greece. The analysis of these scenes was hampered by the afternoon heating of mountainous areas.

4.2 Demonstration Phase in Summer 1994

In the demonstration phase of the forest fire workstation in summer 1994 (from 5 July 1994 to 15 August 1994), 105 NOAA AVHRR scenes were processed. Thirteen fires were detected in the fully automatic processing of these scenes (table 1, figure 3, left).

Table 1: Fires detected by the prototype system in 1994.

	Acquired at	Latitude	Longitude	Country
1	94-07-05 16:54	62°19'	24°54'	Finland
2	94-07-06 15:00	62°31'	25°32'	Finland
3	94-07-14 17:00	56°54'	24°14'	Latvia
4	94-07-14 13:21	60°06'	30°56'	Russia
5	94-07-14 15:02	59°17'	25°25'	Estonia
6	94-07-15 13:09	60°44'	29°53'	Russia
7	94-07-15 13:09	58°46'	34°03'	Russia
8	94-07-17 12:44	59°08'	37°49'	Russia
9	94-07-17 14:25	55°21'	23°58'	Lithuania
10	94-08-01 14:42	54°31'	20°56'	Russia
11	94-08-02 16:49	65°28'	29°11'	Finland
12	94-08-03 14:17	62°04'	26°55'	Finland
13	94-08-06 17:02	55°22'	24°15'	Lithuania

In table 1, the column "Acquired at" gives the date and time (in UTC) of the NOAA scene where the fire was detected.

A verification was done for all fires that were located in Finland, Estonia or Latvia. All 4 fires located in Finland (verified by the Finnish Ministry of the Interior, Rescue Department) were prescribed (man-made) burnings for forest improvement purposes. One fire was in Estonia. This was verified by the Estonian fire authorities. The fire was a real forest fire. One of the detected fires was in Latvia. Also this was a real fire (verified by the Latvian fire authorities).

4.3 Pilot Phase in Summer 1995

In 1995, the system was demonstrated in a pilot phase. Between 4 July and 8 September, the alert messages generated by the fully automatic fire detection system were sent by telefax to the Helsinki Regional Dispatching Centre. There the location of the detected fire was used to redirect the fax to the regional dispatching centre where the fire was located or to the country where the fire was located. This redirected fax included a request for verification of the fire.

In total 205 NOAA AVHRR scenes were processed between 4 July and 8 September. The system detected over 14 000 hot spots. Only 85 of the hot spots were classified as real fires (figure 3, right). Table 2 shows the fires detected in the area where verification was possible. Data for the remaining fires can be found in World Wide Web, URL:
http://www.vtt.fi/aut/ava/rs/proj/fire/fires95.html

Table 2: Fires detected by the prototype system in 1995 in areas where verification is possible.

Acquired at	Latitude	Long.	Country	V
95-07-09 08:16	56°27'	22°11'	Latvia	P
95-07-11 06:21	59°56'	23°09'	AHK/Tammisaari	I
95-07-12 15:51	62°25'	27°40'	AHK/Varkaus	P
95-07-13 17:10	60°36'	25°34'	AHK/Porvoo	P
95-07-20 17:29	61°08'	32°25'	Carelia/Russia	-
95-07-23 15:12	60°37'	24°43'	AHK/Riihimäki	F
95-07-27 15:25	62°58'	26°34'	AHK/Kuopio	P
95-07-28 16:43	63°04'	25°48'	AHK/Äänekoski	P
95-07-29 17:13	62°19'	25°12'	AHK/Jyväskylä	P
95-07-30 08:45	58°41'	25°00'	Estonia	2
95-07-31 15:38	63°00'	28°24'	AHK/Kuopio	P
95-08-02 16:35	61°24'	23°39'	AHK/Tampere	P
95-08-02 18:01	65°07'	29°44'	AHK/Kajaani	P
95-08-02 18:01	61°22'	23°29'	AHK/Tampere	P
95-08-03 16:13	62°24'	24°54'	AHK/Jämsä	P
95-08-06 16:48	56°27'	23°57'	Latvia	P
95-08-16 16:30	61°24'	23°39'	AHK/Tampere	P
95-08-19 15:25	64°42'	24°31'	AHK/Raahe	I
95-08-23 15:38	59°17'	27°50'	Estonia	-
95-09-03 16:39	64°43'	24°31'	AHK/Raahe	I
95-09-04 16:17	60°38'	26°49'	AHK/Kotka	?

Key for the verification results (column V above):

P	=	prescribed burning
I	=	industrial site
-	=	verification pending
F	=	forest fire
2	=	false alarm in an area where 2 days earlier had been a forest fire
?	=	reason for hot spot not known

In table 2, the regional dispatching centre (AHK) is indicated for fires in Finland. The verification results in column V of table 2 are mainly based on the immediate feed-back from the regional dispatching centres. These verification results were augmented after the fire season in cases where no answer was received and in cases where other problems were encountered.

In the screening of false alarms, the elimination of cases where the imaging geometry was close to specular reflection was the most efficient single criterion. A more detailed analysis

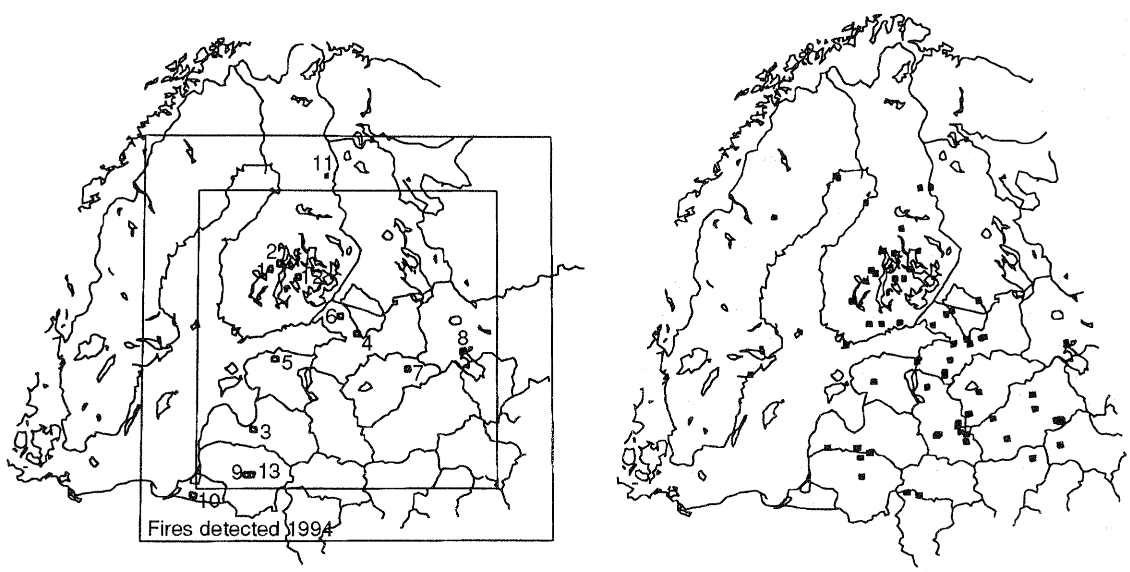

Figure 3: Fires detected in experiments in 1994 (left) and 1995 (right).

of the performance of the false-alarm criteria can be found in (Rauste *et al* 1996).

5 DISCUSSION

Most of the hot spots identified as false alarms were in those areas of the input scene where the imaging geometry is close to specular reflection. If data from AVHRR or a similar sensor (a wide field of view, pointed to nadir) is used these areas cannot be avoided in the input data stream. The imaging geometry can be used (as done in this study) to find false alarms due to reflections from clouds or (possibly sub-pixel) water surfaces. If a satellite system is designed specifically for fire detection, this type of false alarms can be avoided for instance by tilting the sensor axis away from sun when sun-synchronous orbits are used.

The experiments with the automatic fire detection system have shown that the total response time of the system (from the start of the fire to the delivery of alert message to the local fire authorities) is a critical factor when evaluating the feasibility of the system. The total response time can be enhanced

- by enhanced satellites (with increased spatial resolution and mid-infrared dynamic range),
- by increasing the number of satellites used,
- by speeding up the feeding of satellite data into the system, and
- by sending the alert messages from a fully automatic system directly to the local fire authorities.

Development plans of the system include:

- integration of an automatic GCP (ground control point) based refinement of the geo-coding,
- elimination of known industrial sites as false alarms,
- increase of the input sub-scenes, and
- sending of direct automatic alert-messages (with the fire spot indicated on a map) by telefax to regional dispatching centres.

Satellite based fire detection is a feasible tool in the *Boreal* forest zone to augment fire surveillance by other means such as air surveillance. This requires that the supply of mid-infrared satellite data in day time during the summer season is frequent enough.

6 ACKNOWLEDGEMENTS

The author would like to thank the Finnish Ministry of the Interior for funding the work described in this paper. The author would also like to thank Harry Frelander (of the Ministry), Kristiina Soini (of the Finnish Meteorological Institute), and Väinö Kelhä (of the VTT Automation), who have contributed to the development of the fire detection system in the steering group of the project.

The author would also like to thank the people who have contributed to the work in the three demonstration phases of the system, among them especially Einar-Arne Herland, Seppo Väätäinen, Ari Westerlund, Juha-Petri Kärnä, and Mikael Holm in VTT Automation, Timo Kuoremäki in Finnish Meteorological Institute, Arto Ruokari and Markus Grönholm in Helsinki Regional Dispatching Centre, and Karin Vikström, Janne Koivukoski, and Tero Paasiluoto in the Finnish Ministry of the Interior.

The work of numerous individuals who contributed to the verification of the fires (in Finland, Estonia, and Latvia) observed by the fire detection system is also acknowledged.

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