Earth Observation Software System for Fire Monitoring

M. Lazarova, B. Miloshevska, D. Ivanova, Y. Pavlov, M. Damyanov

Key Words: *Remote sensing; fire detection and monitoring; MODIS, multitemporal analysis; burn area.*

Abstract. *The paper presents fire detection and monitoring software system based on satellite data acquired by remote sensing of the Earth. Fire detection is based on data downloaded by MODIS Rapid Response System and uses contextual detection algorithm. The system provides visual localization of the detected fires as well as sound alarm, e-mail and sms alert. Multitemporal analyses are utilized for monitoring the dynamics of the fire front. Deforestation resulting of the fire burn area is estimated using NDVI multitemporal comparison. A history of the detected fires as well as information about date/time of the fire occurrence and localizations is also provided for the purposes of fire pattern analysis.*

1. Introduction

Fire has been a major influence on the development and management of many of the world's forests [1]. Wildfires are a global phenomenon which not only destroy natural vegetation but also pose enormous danger to wildlife as well as to human life and property. Every year millions of hectares of the world's forests are consumed by fire, which results in enormous economic losses because of destroyed timber, burnt housing, high costs of fire suppression, damage to environmental, recreational and amenity values and loss of life and livelihoods. In addition biomass burning by fires has been identified as a significant source of aerosols, carbon fluxes, and trace gases which pollute the atmosphere and contribute to radiative forcing responsible for global climate change [2].

Timely and accurate detection of fires has become an issue of considerable importance. Various international organizations have recognized the need for fire detection and monitoring and have dedicated programmes, committees and projects to support fire management, policy decision-making and global change research [3, 4].

The most feasible and practical methods of regional and global active fire detection rely on satellite data. Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object under investigation [5]. Satellite images and especially freely available satellite data provided to the end users immediately after their acquisition are an effective and economic alternative for fire detection and monitoring.

Fire detection and monitoring is aimed at mapping hotspots that correspond to fires and monitoring the fire dynamics providing some fire parameters. Most fire detection systems generate an alarm condition in response to a measured environmental factor that indicates the existence of a fire. Automatic fire recognition is a key issue in the attempts to increase the response speed in fire detection using remote sensing of the Earth.

Detection and monitoring algorithms have been developed and applied over several satellite sensors carried on board of different satellites: GOES [6], MSG [7], AVHRR [8, 9], MODIS [10,11], BIRD [12].

The fire detection algorithms suggested in the literature can be broadly classified as either threshold based or contextual algorithms [13]. All fire detection algorithms rely on hotspot detection using data acquired in several visible and infrared channels with fixed or contextual thresholds. Threshold based algorithms analyse the brightness temperature and/or reflectance in one or more spectral bands and detects fires wherever values calculated exceeds or falls below a certain predetermined threshold value. The contextual fire detection algorithms involve spatial and temporal background statistical analysis in local neighbourhood of the candidate pixel in order to improve the active fire detection.

The paper presents a software system developed for the purposes of fire detection and monitoring based on satellite data acquired by remote sensing of the Earth. The MODIS sensors on board of satellites Terra and Aqua are utilized. Data are downloaded by the rapid response system providing ftp access to the most recently acquired images. Fire detection is based on a contextual algorithm. After processing the data the detected fires are mapped and the system provides visual localization as well as several means of alarms: a sound alarm, an e-mail and sms alert. Multitemporal analyses are utilized for monitoring the dynamics of the fires over a sequence of downloaded images. Deforestation resulting of the fires is estimated using NDVI multitemporal comparison. A history of the detected fires as well as information about date/time of the fire occurrence and localizations is also provided for the purposes of fire pattern analysis.

* The software system described in the paper has represented Bulgaria at the worldwide Microsoft's student competition Imagine Cup'08 finals in Paris, France in July 2008 and has won the Engineering Excellence Award.

2. Data and Methods

Remote sensing data. The Moderate Resolution Imaging Spectroradiometers (MODIS) on NASA's Earth Observing System (EOS) satellites Terra and Aqua are semi-operationally used for worldwide fire detection. MODIS was launched onboard the Terra spacecraft on 18 December 1999 and onboard the Aqua spacecraft on 4 May 2002. MODIS covers most of the Earth twice a day: once during the daytime and once at night. MODIS sensors on Terra and Aqua together cover all parts of the Earth at least four times a day: twice during the day and twice during the night. The coverage frequency increases additionally with the latitude due to overlapping of the MODIS imaging swaths. MODIS has 36 spectral channels in three spatial resolutions: 250m at red and near infrared (NIR) channels, 500m at five channels from blue to short wave infrared (SWIR) and 1 km at the remaining 29 channels from blue to thermal infrared (TIR). Active fire products [14] are one of the operational standard products generated from MODIS, which shows great potential for global fire detection and monitoring.

Image acquisition. The MODIS Rapid Response System [15] was developed to provide daily satellite images of the Earth's landmasses in near real time. True-color, photo-like imagery and false-color imagery are available within a few hours of being collected making the system a valuable resource for organizations like the U.S. Forest Service and the international fire monitoring community, who use the images to track fires; the United States Department of Agriculture Foreign Agricultural Service, who monitors crops and growing conditions; and the United States Environmental Protection Agency and the United States Air Force Weather Agency, who track dust and ash in the atmosphere. The science community also uses the system in projects like the Aerosol Robotic Network (AERONET) which studies particles like smoke, pollution, or dust in the atmosphere.

Fire detection algorithm. The fire detection algorithms using remote sensing data are developed and applied at both regional and global scale utilizing data from different sensors. Because of its high temperature fire emits thermal radiation with a peak in the MIR region in accordance with Planck's theory of black-body radiation. Therefore fire sensing is often done with data in the MIR to TIR (usually around 3.7 to 11 mm) although other spectral bands (mainly in the visible and NIR) may play complementary roles such as for distinguishing fires from other features including smoke and particles emitted by fires. In order to optimize fire detection and to avoid marking pixels as potential fire in areas where fires are improbable masks are included in the processing chain: water mask, desert mask, cloud mask, sun light.

All fire detection algorithms comprise the following consequent stages to detect and precise potential fire places [16]:

- Potential fire detection: initial tests based on simple thresholds to identify potential fire pixels.
- Background selection: identifying neighboring pixels that qualify for inclusion in the background sample for contextual algorithms. The search window size grows until the minimum number of pixels required to constitute sufficient background sample is found, or until the maximum preset window size is reached.
- Main fire detection: tests to confirm whether a candidate pixel is likely to be true fire.
- Filter hot surfaces: tests to eliminate high temperature surfaces that most probably are not fire.
- Filter clouds: tests to filter pixels likely to correspond to clouds.
- Filter reflective surfaces: Test to eliminate pixels that, because of high reflectivity, could be misclassified as fire pixels.
- Filter sun glint: tests to eliminate pixels affected by sun glint due to specular reflection, which occurs when the satellite view angle to a given pixel equals the solar zenith angle.
- Other detection criteria: complementary tests to improve the accuracy of the detection.

The algorithm used in the presented software system is based on the algorithm known as MODIS version 4 [11] that was originally suggested in [17].

MODIS fire detection algorithm is based on the data from 7 channels (*table1*).

Table 1. Spectral channels for fire detection using MODIS on EOS – Terra/Aqua

Channel No.	Spectral range	Wavelength [μm]	Spatial resolution [m]
1	Visible red	0.620 – 0.670	250
2	Near infrared	0.841 – 0.876	250
7	Medium infrared	2.105 – 2.155	500
21	Medium infrared	3.929 – 3.989	1000
22	Medium infrared	3.929 – 3.989	1000
31	Thermal infrared	10.780 – 11.280	1000
32	Thermal infrared	11.770 – 12.270	1000

The MODIS swath image is classified into one of the following classes: missing data, cloud, water, non-fire, fire or unknown according to the following conditions and tests:

- Cloud masking: different conditions are tested for daytime and nighttime pixels in order the pixel to be considered cloud-obstruct:

for daytime pixels:

$$(P_{0.65} + P_{0.86} > 0.9) \text{ or } (T_{12} < 265K) \text{ or}$$
$$((P_{0.65} + P_{0.86} > 0.7) \text{ and } (T_{12} < 285K))$$

where $P_{0.65}$ and $P_{0.86}$ are the reflections of channel 1 and channel 2 respectively, T_{12} is the temperature registered in channel 32 and K denotes the temperature measured in Kelvin degrees;

for nighttime pixels: $T_{12} < 265K$.

- Water masking: pixels are identified using the 1 km prelaunch land/sea mask contained in the MODIS geolocation product;

- Identification of potential fire pixels: all pixels that do not pass the following tests are preliminary classified as non-fire: T_4>310K, $T_4 - T_{11}$>10 K, $P_{0.86}$<0.3 for daytime pixels T_4>305K for nighttime pixels.
- Absolute threshold test: a fire pixel is detected if the following condition is satisfied:

$$T_4 > 360K \text{ (320K at night).}$$

- Context definition: background pixels are the pixels in local neighborhood of size maximum 21x21 that: (1) contain usable observations, (2) are located on land, (3) are not cloud-contaminated, (4) are not background fire pixels:

background fire pixel test:

T_4>325K and $T_4 - T_{11}$>20K for daytime pixels or T_4>310K and $T_4 - T_{11}$>10K for nighttime pixels.

- Relative threshold test: a pixel is marked as fire if the following conditions are satisfied:

$$T_4 > \text{mean}(T_4)+3\text{stddev}(T_4) \text{ or } T_4>330 \text{ (day)}$$
$$T_4 > \text{mean}(T_4)+3\text{stddev}(T_4) \text{ or } T_4>315 \text{ (night)}$$

AND

$$\Delta T>\text{median}(\Delta T)+3\text{stddev}(\Delta T) \text{ or } \Delta T>25K \text{ (day)}$$
$$\Delta T>\text{median}(\Delta T)+3\text{stddev}(\Delta T) \text{ or } \Delta T>10K \text{ (night)}$$

where ΔT denotes the temperature difference $T_4 - T_{11}$, mean, median and stddev are calculated for the selected background pixels of the tested potential fire pixel.

The remote sensing based fire detection requires the following operations to be performed (*figure 1*):

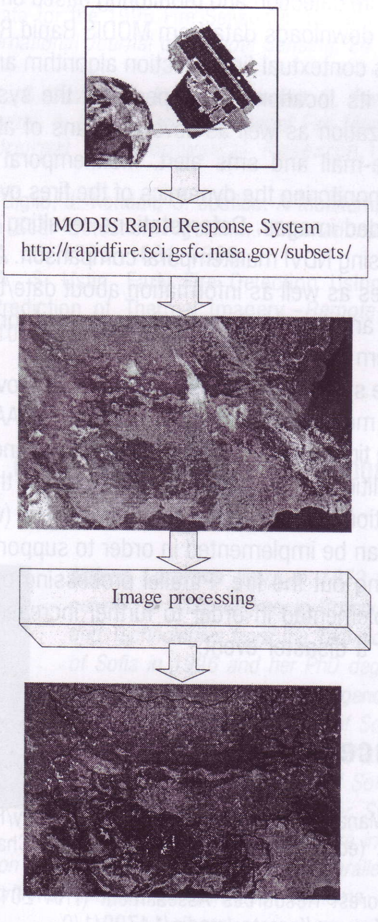


Figure 1. Fire detection process

- Satellites, orbiting the Earth scan and send data to receiving stations on the ground and then data are published on ftp servers;
- Data are downloaded and processed automatically for detection of potential fires.

Multitemporal analysis. The multitemporal fire detection is complicated by both spatial and temporal variability of background surface properties, weather influences, viewing geometries, sensor noise, residual misregistration, and other factors [19]. Multitemporal comparison of the results of the fire detection based on image swaths acquired as a time sequence provides possibilities for monitoring the dynamics of the fire front (*figure 2*).

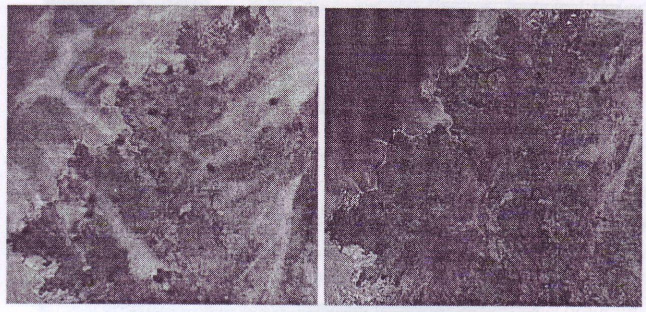


Figure 2. Multitemporal comparison of fire hotspots detected

Deforestation. A burn area detection algorithm for MODIS fire products is suggested in [18] detects persistent changes in a daily vegetation-index time series:

$$\mathrm{VI} = \frac{\rho_5 - \rho_7}{\rho_5 + \rho_7}$$

where VI is a vegetation index calculated, ρ_5 and ρ_7 denote respectively MODIS band 5 (1.2μm) and band 7 (2.1μm) surface reflectance. This index shows a significant decrease following a burn.

The general detection approach first derives a summary map of persistent change from the VI time series and then use spatial and temporal active fire information to guide the statistical characterization of burn-related and non burn-related change within the scene.

3.System Architecture

The software system for fire monitoring is developed using the latest software technologies. These make possible the implementation of the complex functionality of the system and the state of the art, user friendly graphical user interface that facilitates the exploitation of the complex system functionality.

The main system functionalities are presented in *figure 3*. The system interface is shown in *figure 4* and *figure 5* shows the Microsoft Virtual Earth based map visualization of the detected fire.

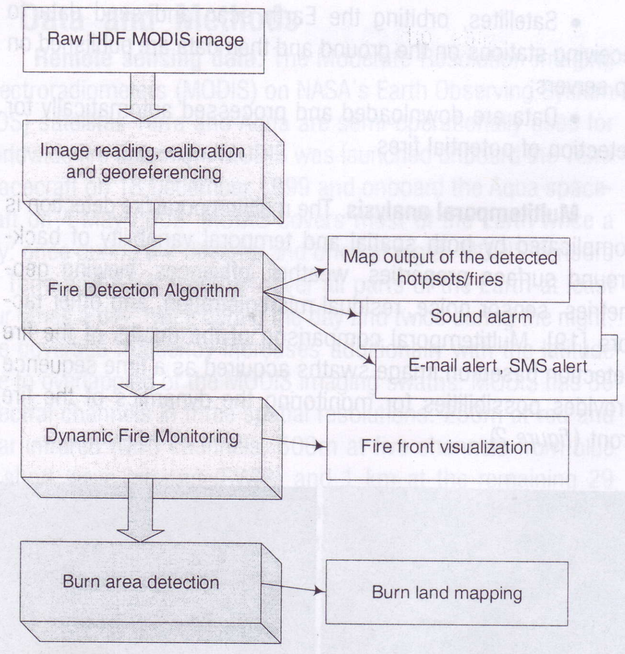


Figure 3. Main functions and outputs of the system

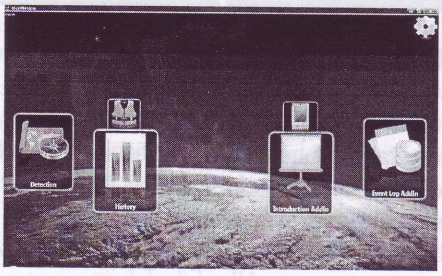


Figure 4. Main window of the system's graphical user interface

Figure 5. Visualization of the detected fire

Level 1B MODIS data are used for active fire detection. The data are downloaded in the form of HDF files from the FTP servers of the MODIS rapid response system. The HDF files are read and data are prepared for feeding to the fire detection algorithm. A .NET library named HdfEosNet is developed as part of the fire detection system and is used for reading the HDF-EOS format that is also used by NASA for storing MODIS data. HdfEosNet employs SmartCache technology to allow the system to be run on lower-end computers.

The software system developed has a flexible AddIn architecture providing easy future extensions:

- New functionality can be added without stopping the application.
- Easy extension and incremental adoption of the system features.
- An integrated user experience is provided.

Due to the AddIn system architecture and the HdfEosNet library developed, new detection algorithms can be easily implemented and added to the system.

Experiments were made with the developed software system using several images from different places around the Earth. The comparison of the results of the fire detection at different time and places around the Earth and the validation with historical ground data for past fire events shown that the implemented fire detection algorithm provides the accuracy of the NASA active fire products. Moreover the system provides near real time results that is fire map is acquired about 5 hours earlier than the NASA's results of MODIS based active fire detection.

4. Conclusion

The developed software system provides possibilities for operational fire detection and monitoring based on satellite data. The system downloads data from MODIS Rapid Response system, applies contextual fire detection algorithm and in case fire is detected its location is mapped and the system provides visual localization as well as several means of alarm: a sound alarm, an e-mail and sms alert. Multitemporal analyses are utilized for monitoring the dynamics of the fires over a sequence of downloaded images. Deforestations resulting of the fires is estimated using NDVI multitemporal comparison. A history of the detected fires as well as information about date/time of the fire occurrence and localizations is also provided for the purposes of fire pattern analysis.

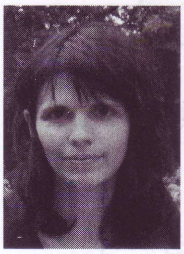
Future system extension is intended to provide fire detection using more satellite systems (MSG, NOAA) in order to increase the time resolution of the data acquired and to strengthen the possibilities for operational monitoring of the fire parameters. Additional Reaction Assistance System (with Real time Tracking) can be implemented in order to support the fire fighters in putting out the fire. Parallel processing of satellite data can be implemented in order to further increase the speed of warning for a disaster event.

References

1. FAO Fire Management, http://www.fao.org/forestry/Firemanagement.
2. Levine, J. (edt.). Biomass Burning and Global Change. MIT Press, 1996.
3. Global Forest Resources Assessment (FRA 2010). April 2008, http://www.fao.org/forestry/media/14799/1/0.
4. GOFC/GOLD Fire Monitoring and Mapping. http://gofc-fire.umd.edu.

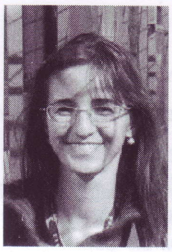
5. Lillesand, T., R. Kiefer, J. Chipman. Remote Sensing and Image Interpretation. Wiley, 2003.
6. Prins, E., W. Menzel. Geostationary Satellite Detection of Biomass Burning in South America.– International Journal of Remote Sensing, 13, 1992, 2783–2799.
7. Calle, A., J. Casanova, A. Romo. Fire Detection and Monitoring Using MSG Spinning Enhanced Visible and Infrared Imager (SEVIRI) Data.– *Journal of Geophysical Research*, 111, 2006,1–13.
8. Flasse, S., P. Ceccato. A Contextual Algorithm for AVHRR fire Detection.–*International Journal of Remote Sensing*, 17, 1996, 419–424.
9. Li, Z., Y. Kaufman, C. Ichoku, R. Fraser, A. Trishchenko, L. Giglio, J. Jin, X. Yu. A Review of AVHRR-based Active Fire Detection Algorithms: Principles, Limitations, and Recommendations. In F. Ahern, J. Goldammer, C. Justice (eds.). Global and Regional Vegetation Fire Monitoring from Space: Planning and Coordinated International Effort. The Hague: SPB Academic Publishing, 2001, 199–225.
10. Justice, C., L. Giglio, S. Korontzi, J. Owens, J. Morisette, D. Roy, J. Descloitres, S. Alleaume, F. Petitcolin, Y.Kaufman. The MODIS Fire Products.–*Remote Sensing of Environment*, 83, 2002, 244–262.
11. Giglio, L., J. Descloitres, C. Justice, Y. Kaufman. An Enhanced Contextual Fire Detection Algorithm for MODIS.–*Remote Sensing of Environment*, 87, 2003, 273–282.
12. Briess, K., H. Jahn, E. Lorenz, D. Oertel, W. Skrbek, B. Zhukov. Fire Recognition Potential of the Bi-spectral InfraRed Detection (BIRD) Satellite. International Journal on Remote Sensing, 24, 2003, 865–872.
13. Justice, C., P. Dowty (eds.). IGBP-DIS Satellite Fire Detection Algorithm Workshop Technical Report. IGBP-DIS Working Paper 9, NASA/GSFC, Greenbelt, MD, 1993, 88.
14. MODIS Fire and Thermal Anomalies. http://modis-fire.umd.edu.
15. MODIS Rapid Response System. http://rapidfire.sci.gsfc.nasa.gov.
16. Ichoku, C., Y. Kaufman, L. Giglio, Z. Li, R. Fraser, J.-Z. Jin, W. Park. Comparative Analysis of Daytime Fire Detection Algorithms Using AVHRR Data for the 1995 Fire Season in Canada: Perspective for MODIS.–*International Journal of Remote Sensing*, 24, No8, 2003, 1669–1690.
17. Kaufman, Y., C. Justice, L. Flynn, J. Kendall, E. Prins, L. Giglio, D. Ward, W. Menzel, A. Setzer. Potential Global Fire Monitoring from EOS-MODIS.–*Journal of Geophysical Research*,103, 1998, 32215–32238.
18. Roy, D., L. Giglio, J. Kendall, C. Justice. A Multitemporal Active-fire Based Burn Scar Detection Algorithm.–*International Journal of Remote Sensing*, 20, 1999, 1031–1038.
19. Koltunov, A., S. Ustin. Early Fire Detection Using Non-linear Multitemporal Prediction of Thermal Imagery.–*Remote Sensing of Environment*, 110, No1, 2007,18–28.

Manuscript received on 09.10.2008



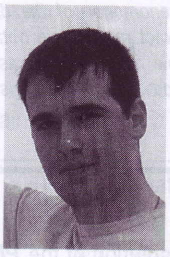
Milena Lazarova *(born in 1972 in Sofia) received her MSc degree in Computer Systems and Technologies from the Technical University of Sofia in 1996 and her PhD degree in Computer Science (Artificial Intelligence Systems) from the Technical University of Sofia in 2000. She is an Assist.Prof. in the Dept. Computer System, Technical University of Sofia and Vice-Dean of Faculty of Computer Systems and Control. Her research areas are in the filed of pattern recognition and multispectral classification, parallel computing and parallel algorithms, geographic information systems.*

Boriana Miloshevska *has BCs degree in Computer Systems and Technologies from the Technical University of Sofia in 2007 and is currently MSc student in the Faculty of Computer Systems and Control, Technical University of Sofia. Her interests are in the field of new information and programming technologies.*



Dobromira Ivanova *has BCs degree in Computer Systems and Technologies from the Technical University of Sofia in 2007 and is currently MSc student in the Faculty of Computer Systems and Control, Technical University of Sofia. Her interests are in the field of visualization technologies.*

Yordan Pavlov *has BCs degree in Computer Systems and Technologies from the Technical University of Sofia in 2007 and is currently MSc student in the Faculty of Computer Systems and Control, Technical University of Sofia. His research interests include parallel programming and parallel algorithms, new information technologies, geographic information systems, project management.*



Martin Damyanov *has BCs degree in Computer Systems and Technologies from the Technical University of Sofia in 2007 and is currently MSc student in the Faculty of Computer Systems and Control, Technical University of Sofia. His research interests are in the field of software architectures and parallel programming.*

Contacts:
Dept. Computer Systems,
Faculty of Computer Systems and Control,
Technical University of Sofia Tel.: +359 895588703,
e-mail: milaz@tu-sofia.bg