Efficient Forest Fire Detection System: A Spatial Data Mining and Image Processing Based Approach

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Summary
The drastic ascent in the volume of spatial data owes its growth to the technical advancements in technologies that aid in spatial data acquisition, mass storage and network interconnection. Thus the necessity for automated detection of spatial knowledge from voluminous spatial data arises. Fire plays a vital role in a majority of the forest ecosystems. Forest fires are serious ecological threats that result in deterioration of economy and environment apart from jeopardizing human lives. Thus forest fires need to be detected as early as possible in order to inhibit from being spread. This paper intends to detect forest fires from the forest spatial data. The approach makes use of spatial data mining, image processing and artificial intelligence techniques for the detection of fires. A fuzzy rule base is formed for the detection of fires, from the spatial data with the presence of fires. The digital images from the spatial data are converted to $YCbCr$ color space and then segmented by employing anisotropic diffusion to identify fire regions. Subsequently, a fuzzy set is created with the color space values of the fire regions. Further, fuzzy rules are derived on basis of fuzzy logic reasoning. Extensive experimental assessment on publicly available spatial data illustrated that the proposed approach efficiently detects forest fires.

Key words:
Data mining, Spatial data, Remote Sensing, Forest Fire Detection, Segmentation, Anisotropic diffusion, Fuzzy set, Fuzzy logic, Fuzzy rule base.

1. Introduction

The advancements in scientific data collection have led to huge and continuously ascending amount of data making it unfeasible to be interpreted manually. Hence, the development of new techniques and tools in support of humans, aiding in the transformation of data into beneficial knowledge has been the center of the comparatively new and interdisciplinary research area called the “knowledge discovery in databases (KDD)” [3]. Knowledge discovery in databases can be defined as the “The non-trivial extraction of implicit, previously unknown, and potentially useful information from databases” [5]. Data selection, data reduction, data mining, and the assessment of the data mining results form the integral part of the interactive and iterative KDD process. Nevertheless, data mining is the core and vital step that involves the examination and discovery algorithms that under tolerable computational efficiency limitations generate a specific enumeration of patterns over the data [4, 5].

Data mining is a scheme that integrates machine learning, pattern recognition, statistics, databases, and visualization techniques into one so as to facilitate the efficient information extraction from large databases [6]. Numerous fields like marketing, manufacturing, process control, fraud detection and network management have benefited from the data mining techniques. Apart from this, a huge variety of data sets like market basket data, web data, DNA data, text data, and spatial data [7] have profited as well. Despite the number of researches in Knowledge discovery being high, knowledge discovery in spatial databases was dealt with only in very few [3]. The advancements in scientific data collection have led to huge and continuously ascending amount of spatial data [1]. Thus the necessity, for automated discovery of spatial knowledge from enormous amount of spatial data, arises.

The procedure of identifying previously hidden yet beneficial information from huge databases is known as spatial data mining. Owing to the complexity of spatial data types, spatial relationships, and spatial autocorrelation the extraction of patterns of benefit and interest from the spatial databases is comparatively tedious than that of the conventional numeric and categorical data [2]. Spatial data mining technologies can aid in the comprehension of spatial data, discovery of relationships among spatial and non-spatial variables, determination the spatial distribution patterns of particular phenomena besides supporting the envisagement of the trends of the patterns. Spatial statistics and data mining form the elemental parts of spatial data mining. Spatial data mining techniques encompass visual interpretation and analysis, spatial and attribute query and selection, characterization, generalization and classification, detection of spatial and non spatial association rules, clustering analysis and spatial regression besides a wide variety of other fields [8].

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Spatial data mining and relational data mining differ from one another owing to the fact that in the former the attributes of the neighbors of some object of interests need to be taken into account as well since they have a notable influence on the object [9]. Certain features of spatial data that prohibit the usage of regular data mining algorithms include: i) rich data types (e.g., extended spatial objects) ii) inherent spatial relationships between the variables, iii) observations that are dependant on other factors, and iv) Spatial autocorrelation among the features [2]. Precision agriculture, community planning, resource discovery and numerous other areas can benefit greatly from the extraction of patterns of interest and rules from the spatial data sets like the remotely sensed imagery and related ground data [10]. Spatial data mining is extensively applied in change detection, modeling deforestation, disaster analysis, forest fire detection and other related fields. Our research focuses on the discovery of forest fires from the spatial data analogous to forest regions.

1.1 Forest Fires

Fires have been a source of trouble for a long time now. Fires have remarkable influence over the ecological and economic utilities of the forest being a principal constituent in a huge number of forest ecosystems [11]. Forest and wild land fires have been witnessed in the past. They have played a remarkable role in determining landscape structure, pattern and eventually the species composition of ecosystems. Controlling factors like the plant community development, soil nutrient availability and biological diversity forms the integral part of the ecological role of forest fires [13]. Since the forest fires cause notable economical and ecological damage despite jeopardizing human lives they are considered as a significant environmental issue [12]. Annually several hundred million hectares (ha) of forest and other vegetation are deteriorated by the forest fires [14].

Intermittently forest fires have compelled the evacuation of vulnerable communities besides heavy damages amounting to millions of dollars. 19.27% or 63.3 million ha of the Indian land has been classified into forest area as per the report of the Forest Survey of India [40], of which 38 million ha alone are hoarded with resources in abundance (crown density above 40%). Thus the country's forests face immense difficulty. Indian forests are also in jeopardy due to the forest fires leading to their degradation [15]. Fires caused huge damage in the year 2007 affecting huge territories besides notable number of human casualties [16]. Forest fires pose continuous threats to ecological systems, infrastructure and human lives. Detecting the fires at their early stages and reacting in a fast pace so as to prevent the spread is the only viable and effective option to minimize the damage. Henceforth huge efforts have been put forth to facilitate early detection of forest fires, conventionally being carried out with the aid of human surveillance [17]. Forest fire, Drought, Flood and many other phenomena particularly the ones with huge spatial extent are some of the spatial phenomena that posses predictable spatial patterns that are noticeable through remote sensing Images/products.

1.2. Our Contribution

The primary intention of this paper is to obtain information from spatial data and aid in identifying the spots vulnerable to forest fire with the aid of spatial data mining, image processing and artificial intelligence techniques. We have presented a system that is capable of detecting fires from the spatial data of the respective forest regions. The input fed to the system is the spatial data that corresponds to the forest regions and fire detection is carried out with the aid of digital images. The images prone to fires are utilized in the formation of fuzzy rule base so as to identify the fires. The system begins with the conversion of digital images from spatial data to $YCbCr$ color space. Segmentation of the image in $YCbCr$ color space is carried out with the aid of the renowned anisotropic diffusion approach. This will result in fragments of the image that contains fire prone segments. The fuzzy set and then the fuzzy rule base (based on the fuzzy logic reasoning) are formed by employing the "C_r" value from the $YCbCr$ color space of the fire regions. The detection of forest fires employs the derived fuzzy rules. The performance of proposed approach in the detection of forest fire is improved, which is illustrated by experimental evaluation on the publicly available spatial data.

The rest of the paper is organized as follows. Section 2 presents a brief review of some of the previous works in forest fire detection. The proposed efficient forest fire detection system is presented in Section 3. The experimental results are given in Section 4 and Section 5 sums up the conclusion.

2. Related Works

In Ollero et al. [32], a scheme of multi-sensorial integrated systems for early detection of forest fires has been presented. The system presented by the authors employs infrared images, visual images, data from sensors, maps and models in their system. According to their study, to facilitate the reduction of perception errors and the improvement in reliability of the detection process, the integration of sensors, terrain knowledge and expertise is necessary.

In Louis Giglio et al. [33], an improved fire detection algorithm that offers increased sensitivity to smaller, cooler fires as well as a significantly lower false alarm rate has been presented. The authors employ the theoretical simulation and high-resolution Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) scenes to establish the performance of their algorithm.

In Seng Chuan Tay et al. [34], an approach to reduce the false alarms in the hotspots of forest fire regions has been presented, which employs geographical coordinates of hot spots in forest fire regions in the detection of likely fire points. In order to determine regular patterns in the derived hotspots and classify them as false alarms on the assumption that fires usually do not spread in regular patterns such as in a straight line, the authors use clustering and Hough transformation. The application of spatial data mining for the reduction of false alarm from the set of hot spots derived from NOAA images is demonstrated in their work.

In Young Gi Byun et al. [35], a graph-based forest fire detection algorithm on the basis of spatial outlier detection methods has been presented. The authors have performed spatial variation in their algorithm by the use of spatial statistics. When compared with the MODIS fire product provided by the NASA MODIS Science Team, the algorithm presented show higher user and producer accuracies. The authors prove that the ordinary scatter plot algorithm was inefficient owing to its insensitivity to small fires, while Moran's scatter plot was also weak owing to the absence of a numerical criterion for spatial variation which necessitated a more and less high commission error.

In Daniela Stojanova et al. [36], an approach to predict forest fires in Slovenia using different data mining techniques has been presented. The predictive models on the basis of data from a GIS (geographical information system) and the weather prediction model - Aladin and MODIS satellite data has been employed by the authors. Three different datasets: one only for the Kras region, one for Primorska region and one for continental Slovenia have been examined by the authors. The authors illustrate that bagging and boosting of decision trees produces the best results in terms of accuracy for all three datasets.

In Yasar Guneri Sahin [37], a mobile biological sensor system for early detection of forest fires, which uses animals as mobile biological sensors, has been presented. The existing animals tracking systems used for zoological studies are the basis of their system. The author demonstrates that the combination of these fields may lead to simultaneous development of animal tracking as well as forest fire detection. A potentially serious forest fires were detected early by the system, by which their effect was reduced, hence the reduction of the speed of global warming was assisted.

In Florent Lafarge et al. [38], a fully automatic method of forest fire detection from TIR satellite images based on the random field theory has been presented. It is demonstrated that the results of the system rely only on the confidence coefficient. The values obtained for both detection rate and false alarm rate were convincing. The estimation of fire propagation direction provided interesting information related to the evolution of the fires, to the authors.

In Movaghati et al. [39], the potential of agents to be applied in processing of remote sensing imagery has been studied. In this paper, an agent based approach for forest fire detection has been presented. In order to determine agent behavioral responses, the tests used in MODIS version 4 contextual fire detection algorithm were utilized by the agents. The performance of their algorithm and that of MODIS version 4 contextual fire detection algorithm and ground-based measurements were compared. Good agreement between the algorithms and field data was shown by the results.

3. Efficient Forest Fire Detection System

This section describes the projected system for efficient forest fire detection. The input fed to the system is the spatial data matching to the forest regions. Data mining, image processing and artificial intelligence techniques support the detection of fire from the images of spatial data. A fuzzy rule base is created to aid the detection. Fuzzy sets and fuzzy rule bases are generated on basis of the images with the presence of fires. The images are segmented in order to facilitate the detection of regions prone to fire. Segmentation is done on the $YCbCr$ color space transformed image. Fuzzy logic reasoning serves as the basis for the derivation of fuzzy rules, from the fuzzy sets, which are eventually utilized in the detection of fires. Following are the chief steps involved in the proposed system

(i) Color space conversion
(ii) Segmentation using Anisotropic diffusion approach
(iii) Fuzzy sets and fuzzy rule base formation

3.1 Color Space Conversion

A means by which the specification, creation and visualization of colors is carried out is known as a color space. A computer may express a color with the aid of the amounts of red, green and blue phosphor emission necessary to match a color. Conventionally color is denoted by three coordinates or parameters [18]. The position of the color in the color space is illustrated by these parameters. The transformation and description of a color from one basis to another is known as color space conversion. Usually color space conversion is carried out while converting an image that is represented in one color space to another color space, the objective being to make the translated image look as identical as possible to the original. RGB, CIE XYZ, CIE YUV, CIE L*a*b*, YCbCr and HSV are some of the wide spread color spaces. In our system, we have converted the images from RGB to $YCbCr$ color space.

At a stage in the development of a world wide digital component video standard, the YCbCr color space was developed as part of ITU-R BT.601 [20]. Video and digital photography systems extensively utilize the YCbCr color space [19]. Y' represents the luma components and Cb and Cr represent blue-difference and red-difference chroma components respectively. In order to distinguish the luma from luminance, which means that light intensity is non-linearly encoded using gamma, the prime (‘) on the Y is used. Chroma Cb and chroma Cr correspond to the U color component and the V component of a general YUV color space. The equations to convert RGB into YCbCr color space are as follows:

$$Y = 0.2989R + 0.5866G + 0.1145B$$
$$C_b = -0.1688R - 0.3312G + 0.5000B$$
$$C_r = 0.5000R - 0.4184G - 0.0816B$$

3.2 Segmentation Using Anisotropic Diffusion

Image segmentation is a low-level image processing task for dividing an image into identical regions [21]. The segmentation results can possibly be employed to identify the regions of interest and objects in the scene that is very advantageous to the subsequent image analysis. Color image segmentation is more tedious when compared to the grey image segmentation owing to the reason that the inherent multi-features not only contain non linear relation individually but also comprise inter-feature dependency between R, G, and B (or $YCbCr$). In our system, we have used anisotropic diffusion approach for the segmentation of images. The segmentation is performed on the YCbCr color space converted image.

Literature studies discuss several models of linear and nonlinear diffusion in order to accomplish image smoothing and segmentation. The nonlinear anisotropic diffusion has been employed by many researchers [22], [23] in their works. The anisotropic diffusion improves the response of edge detection algorithms by smoothing the image interiors to emphasize boundaries for segmentation and by eliminating the spurious detail besides eradicating noise from images [26] efficiently. However, there is a propensity that the low frequency objects that are complex to be dispersed without over-processing the image are left out by the relaxation processes that implement anisotropic diffusion.

Anisotropic diffusion in image processing discretizes the family of continuous partial differential equations, which incorporate both the physical processes of diffusion and the Laplacian. Provided that there are no sinks or sources that exist [24], the following equation formulates the abovementioned process (for any dimension):

$$\frac{\partial}{\partial t} u(\overline{x},t) = div\,(c(\overline{x},t)\,\nabla u(\overline{x},t))$$

Diffusion strength is controlled by $c(x,t)$. Vector x denotes the spatial coordinate(s).The ordering parameter is the variable t . The function $u(x,t)$ is taken as image intensity $I(x,t)$ [25].

3.3. Fuzzy Logic

Lotfi A. Zadeh introduced fuzzy logic in 1965 at the University of California in Berkeley [30]. Fuzzy logic is a multi valued logic that facilitates the definition of intermediate values apart from the typical evaluations such as true/false, yes/no, high/low, etc. In order to facilitate a human-like way of reasoning in the programming of computers notions like rather tall or very fast can be formulated mathematically and processed by them. A distinct way of dealing with a control or classification problems is provided by the Fuzzy logic [27], [28]. Fuzzy logic is employed as a tool in achieving intelligent control. The formation of rule based behavior is facilitated by Fuzzy logic. It is possible to encode the knowledge of an expert into a rule base and utilize the same in decision making. The robustness and customizable properties of Fuzzy logic enhance its degree of freedom of control [29]. The fundamental constituents of a fuzzy logic decision making system include fuzzy sets, fuzzy membership functions, and fuzzy rules. An integral part of a fuzzy set is a membership function.

3.3.1. Fuzzy Set, Membership Function And Fuzzy Rule Formation Using Fuzzy Logic Reasoning

The formation of fuzzy sets and fuzzy rule base is described detailed in this sub-section. The fundamental elements of a fuzzy logic system mainly include Fuzzy sets, fuzzy membership functions, and fuzzy rules. There are no defined boundaries for a fuzzy set. The membership functions define the regular and even transition from “belonging to a set” to “not belonging to a set”. The general linguistic expressions such as “the object is dark” or “the object is round” are represented by using the fuzzy sets provided with flexibility by these functions [31].

A fuzzy set can be defined in the following manner: If C is a collection of objects, then a fuzzy set FS in C is defined as a set of ordered pairs:

$$FS = \{(c, mf(c)) | c \in C\}$$

Where, the membership function of c in C is denoted by $mf(c)$, whose value ranges from 0 to 1 and can be considered a degree of truth. Fuzzy rules are the derivatives of these fuzzy sets. Several fuzzy rules can form a fuzzy rule base. The structure of a fuzzy rule is the following:

IF Premise THEN Conclusion

Where the antecedents linked by fuzzy operator AND form the premise.

The fuzzy set is formed with $YCbCr$ color space values of fire prone regions. Then fuzzy rules are derived from this fuzzy set using fuzzy logic reasoning. The $YCbCr$ color space value serves as the Universe of discourse for the fuzzy logic in our system. The ordered pairs of $YCbCr$ color elements and their corresponding degree of membership fuzzy set form the DR(x, x, x). The $YCbCr$ color values are used to define the membership function followed by that the corresponding $YCbCr$ color spaces are used to form the fuzzy sets. Consequently, $YCbCr$ color space is used to define the fuzzy sets for the detection of forest fire from satellite image.

The fuzzy set wherein $YCbCr$ color space is employed for determining the degree of membership is defined as follows:

The fuzzy set that utilizes $YCbCr$ color space in order to estimate the degree of membership is defined subsequently:

$$\begin{aligned}
Fuzzy\,YCbCr(x) = \{&0, if\ ([M_N < valueof(x)]\ and\ [M_X > valueof(x)]);\\
&1, \text{if } ([valueof(x) >= (MY_{\text{Min}}, MCb_{\text{Min}}, MCr_{\text{Min}})] \text{ and } [valueof(\text{x}) <= (MY_{\text{Max}}, MCb_{\text{Max}}, MCr_{\text{Max}})]);\\
&\text{if } ([valueof(\text{x}) >= (\text{M}_{\text{N}})]\ and\ [valueof(x) <= (MY_{\text{Min}}, MCb_{\text{Min}}, MCr_{\text{Min}})]);\\
&((\text{abs}\,(MY_{\text{Min}} - valueof(\text{x})) + \text{abs}\,(MCb_{\text{Min}} - valueof(\text{x})) + \text{abs}\,(MCr_{\text{Min}} - valueof(\text{x})))/3)/100;\\
&\qquad deg\,ree\ of\ membership.\\
&\text{if } ([valueof(x) <= (M_X)] \text{ and } [valueof(\text{x}) >= (MY_{\text{Max}}, M\text{Cb}_{\text{Max}}, MCr_{\text{Max}})]);\\
&((\text{abs}\,(MY_{\text{Max}} - valueof(\text{x})) + \text{abs}\,(MCb_{\text{Max}} - valueof(\text{x})) + \text{abs}\,(MCr_{\text{Max}} - valueof(\text{x})))/3)/100;\\
&\qquad deg\,ree\ of\ membership.\}
\end{aligned}$$

Where

(x) → Set of selected pixel value

M_N → Minimum value of (x)

M_X → Maximum value of (x)

$M\,Y_{Min}$ →Minimum Median value of Y and defined as

$$M\,Y_{Min} = [(Y_{Min} + Y_{Max})/2] - s$$

$M\,Y_{Max}$ →Maximum Median value of Y and defined as

$$M\,Y_{Max} = [(Y_{Min} + Y_{Max})/2] + s$$

$M\,Cb_{Min}$ →Minimum Median value of Cb and defined as

$$M\,Cb_{Min} = [(Cb_{Min} + Cb_{Max})/2] - s$$

$M\,Cb_{Max}$ →Maximum Median value of Cb and defined as

$$M\,Cb_{Max} = [(Cb_{Min} + Cb_{Max})/2] + s$$

$M\,Cr_{Min}$ →Minimum Median value of Cr and defined as

$$M\,Cr_{Min} = [(Cr_{Min} + Cr_{Max})/2] - s$$

$M\,Cr_{Max}$ →Maximum Median value of Cr and defined as

$$M\,Cr_{Max} = [(Cr_{Min} + Cr_{Max})/2] + s$$

s → Small value varies from 0 to 5

4. Experimental Results

This section contains the results of our experiments. The proposed system is implemented in MATLAB. The publicly available spatial data of forest regions with presence of fire was used in the formation of fuzzy set and fuzzy rule base. Consequently forest spatial data with and without the presence of fires were fed as input to the proposed system. The fires in the data were detected effectively by the proposed system with the aid of the derived fuzzy rules. The results of our approach are depicted in Figure 1. From the results we can conclude that the fire on the images of spatial data has been successfully detected by the proposed system.

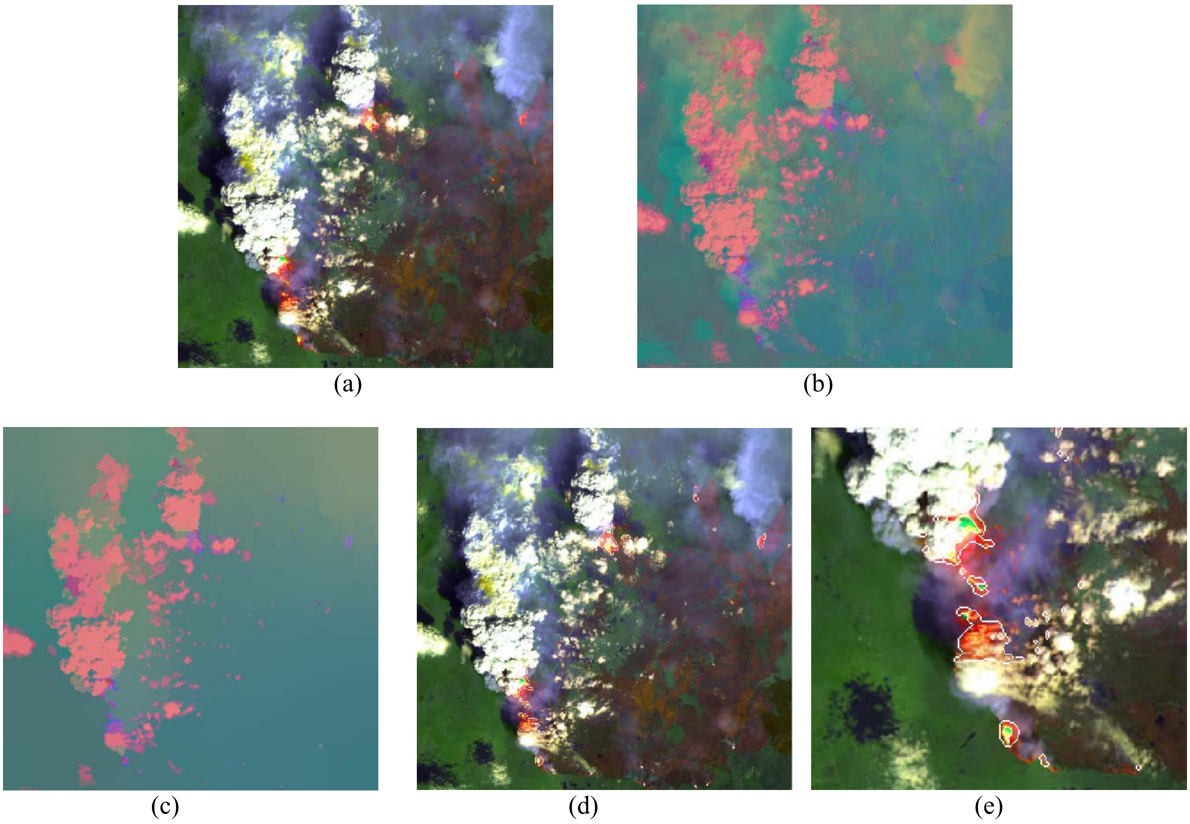

Figure :1 Output representation of forest fire detection process, a) Input Satellite Fire Image, b) YC_bC_r color space converted image, c) Anisotropic Diffusion Segmentation, d) Fire Marked Output Image e) Zoomed view of Fire Marked Output Image

5. Conclusion

The explosive growth of spatial data and widespread use of spatial databases emphasize the need for the automated discovery of spatial knowledge. Fire plays a vital role in a majority of the forest ecosystems. Forest fires cause significant environmental damage while threatening human lives. In the last two decades, a substantial effort was made to build efficient detection tools that could assist Fire Management Systems (FMS). This paper puts forth a novel and efficient approach to detect forest fires from spatial data images. Spatial data mining, image processing and artificial intelligence techniques were exploited to achieve the same. Anisotropic diffusion and fuzzy logic are used for segmentation and identification processes respectively. The C_r value of YC_bC_r color space is utilized in the formation of fuzzy sets and fuzzy rules are derived from the fuzzy sets. The publicly available spatial data are employed in the evaluation process. The fuzzy rules derived using the proposed approach, have successfully detected the forest fires in the spatial data.

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