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Spatial texture based automatic classification of dayside aurora in all-sky images

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ABSTRACT

A spatial texture based representation method including features of intensity, shape and texture, was utilized to characterize all-sky auroral images. The combination of the local binary pattern (LBP) operator and a delicately designed block partition scheme achieved both global shapes and local textures capabilities. The representation method was used in automatic recognition of four primary categories of discrete dayside aurora using observations between years 2003–2009 at the Yellow River Station, Ny-Ålesund, Svalbard. The supervised classification results on labeled data in 2003 were in accordance with the labeling by scientists considering both spectral and morphological information. The occurrence distributions of the four categories were obtained through automatic classification of data between 2004–2009, which confirm the multiple-wavelength intensity distribution of dayside aurora, and further provide morphological interpretation of auroral types.

1. Introduction

1.1. Classification of auroral morphology

The aurora phenomena provide a convenient projection of effects from complex and energetic plasma processes of the outer magnetosphere. Much has been learned about the ionosphere and magnetosphere from auroral events. The spatial structure and temporal evolution of auroral luminosity are ascribed to cumulative effects of the solar wind–magnetosphere interaction and the physics of the magnetosphere–ionosphere interaction.

Two-dimensional morphological information can be captured by all-sky imagers (ASI) with satisfactory spatial and temporal resolution. However, it still remains uncertain what the appearance of the aurora actually represents. The analysis of ASI images is usually performed manually by examining images one by one (Knudsen et al., 2001; Nevanlinna et al., 2001). Nevanlinna et al. (2001) inspected about 100,000 h of all-sky pictures and gave the probability (percentage) of auroral occurrences during clear nights in the dark season. This study is tedious and difficult to repeat (Syrjäsuo, 2001). Sandholt et al. (2004, 2006) analyzed the spatial and temporal structures of the aurora in specified auroral events. However, the attended auroral appearances in case studies are very limited. Certain physical processes in the magnetosphere and ionosphere are responsible for the auroral forms. In earlier studies, there have been several types of aurora identified, which have turned out to be correlated with specific magnetospheric regimes and dynamic activity (Feldstein and Elphinstone, 1992). Variations in the solar wind parameters seem to have a strong influence on auroral type (Kullen et al., 2002). If a limited number of auroral form types can be automatically recognized via computer, then meaningful statistical analysis on a large dataset could be feasible. Thus, a large number of ASI images will be utilized and explored statistically. Synergy between computer vision and space science automate the classification process of these large, cumbersome datasets, thereby alleviating dependency on human effort. The increasing interests in exploring the upper atmosphere lead to the mass accumulation of ASI data, thus necessitating advancements in techniques for automated auroral image classifications.

1.2. Review of classification for aurora

Auroral displays present a variety of forms when observed from the ground and satellite. These forms have been described

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and given distinct terms, some of which have resulted in extensively accepted terminologies. Störmer (1955) defined a scheme of classification in three divisions: forms without and with ray structure, and flaming aurora. For auroral forms without ray structure, arc, band and diffuse patches were further subclassified. Rayed arc, rayed band, rays, corona and drapery are subclasses for auroral forms with rays. This scheme has been widely accepted and has been used for photographically distinguishing aurora of various types. The classification of auroral shapes was introduced by Valance (1974); it includes nine basic shapes. Early in the auroral large imaging system (ALIS) project, an auroral classification scheme of auroral arc, fragmental auroral structure, diffuse aurora and unidentified aurora was suggested by Steen et al. (1997) for the purpose of ALIS data analysis.

Distinct arc-shaped auroral structure is a typical auroral form. There are many studies focusing on its classification. An arc-classification scheme developed by Marklund (1984) reflects the relative influence on the arc electric field pattern from the two current continuity mechanisms, Birkeland currents and polarization electric fields. Kullen et al. (2002) divided polar arcs into five different categories based on their spatial structure and evolution: oval-aligned, bending, moving, midnight, and multiple arcs.

Based on the ground all-sky TV observations at Godhavn, Greenland and simultaneous DMSP particle data, Ayukawa et al. (1996) studied two characteristic polar cap auroras (polar arc and polar coronas) in the pre-noon sector. Yang et al. (2000) used statistical characteristics of the ground aurora data observed at Zhongshan station to propose a scheme consisting of the arc and dayside coronas.

Recently, based on observations acquired from 3-wavelength (427.8, 557.7 and 630.0 nm) all-sky imageries at Yellow River Station (YRS) in Ny-Ålesund, Svalbard, the dayside oval was partitioned into four auroral active regions (Hu et al., 2009). These included the pre-noon green warm spot ('W', 0730–0930 MLT), the midday green gap ('M', 0930–1300 MLT), the post-noon hot spot for auroral emission at 3 wavelengths ('H', 1300–1530 MLT), and the dusk green aurora sector ('D', 1530–1700 MLT). Each region is associated with some kind of typical auroral structures, such as the quickly poleward moving or east–west brightening discrete rayed arcs in region W, drapery-like corona or red radial corona in region M, quasi-periodic brightening rayed bands with poleward moving, isolated brightening rayed bundles or brightening arcs in region H and multiple, parallel east–west extended arcs in region D.

Emergence of various classification schemes has shaped our mentality on designing the following automatic classification strategy. A phenomenon as complex as the aurora cannot be adequately described using intensity or the Kp index. A credible classification strategy therefore, calls for more quantifiable methods. Quantitatively measuring auroral appearance prioritizes itself in ASI image classification. Effective ASI image representation methods are urgently needed.

Syrjäsuo et al. (2001) developed the first search engine for auroral form datasets and to search for the required types of auroras. Kauristie et al. (2001) tested the search engine in real data analysis task in order to explore the relationship between arcs and electrojets. Syrjäsuo et al. (2006) and Syrjäsuo and Donovan (2004a, 2005) used Fourier descriptors of auroral shapes to represent the ASI image. However, the patterns that appear in images share perceived similarities even if the individual shapes are not the same (Syrjäsuo et al., 2006). Fourier descriptors from the extracted shapes eliminate the effects of scale, translation, and rotation so that orientation information associated with physical process is lost. Most importantly, not all auroras have typical extractable contours, as seen in the corona aurora (Ayukawa et al., 1996; Yang et al., 2000). Thus, solely using shape information is insufficient. The shape-based representation method is limited by its nature in real world applications of automatic classification of the ASI image.

Motivated by the deficiency of shape-based methods, a mathematical method called gray level aura matrices (GLAM) (Clausi and Deng, 2005; Haralick et al., 1973) was considered to extract texture information. Unlike shapes, texture describes general image appearance, such as the arranging, occurring and distributing properties of certain structures. It is suitable for describing comprehensive information on auroral morphology and may be more similar to human perception for classifying ASI images. Qin and Yang (2005) and Syrjäsuo et al. (2006) applied the Basic GLAM (BGLAM) to characterize the ASI image. There are two major problems in GLAM-based ASI image representation techniques: (1) Being globally-defined, it does not provide any information about locality. (2) BGLAMs representation is complete. Since an image can be uniquely represented by and then faithfully reconstructed from its BGLAMs, this representation for auroral classification is sensitive to spatial scale variation, orientation, and intensity. In Syrjäsuo and Donovan (2004b), a multiple feature-based auroral image representation method was presented. Features such as image brightness, brightness distribution, and Gabor-filter based texture descriptors were extracted. The classification was based on the linear weighted distance of individual features. Since only the means and standard deviations of the Gabor transform coefficients on different scales and orientations were used, Syrjäsuo and Donovan (2004b) method has very limited capabilities for producing complex auroral patterns.

Unlike most artificial and local textures that possess strong regularity, such as cambric, leather and grass, displays in ASI images are mixtures of bands, patches, texture, and others caused by various underlying physical processes. Therefore, an efficient ASI image representation method should possess the ability to reflect both global shapes as well as local textures. Most classification approaches assume, explicitly or implicitly, that query samples to be classified are identical to training samples with respect to spatial scale, orientation, and gray-scale properties. The available auroral automatic classification methods solely rely on a training set simply by occupying more of the feature space to improve accuracy (Syrjäsuo and Donovan, 2004b). However, a real-world aurora can occur at arbitrary spatial resolutions and rotation, and its formation is subject to varying natural conditions. Even though auroras are of the same type, their spatial scale, orientation, location, and intensity presented in ASI images may vary significantly. Our goal in this paper is to design an effective and robust representation for objectively and quantitatively measuring complex auroral morphology, which makes it possible to correctly and automatically recognize auroral types based on morphology.

1.3. Contributions of this paper

We propose a spatial texture based method to represent the ASI image. The combination of the local binary pattern (LBP) (Ojala et al., 1996, 2002) operator and a delicately designed block partition scheme achieves both global shapes and local textures representations. While the LBP representation sacrifices global spatial information, partition scheme compensates for this loss, while reserving geometric invariance properties within local areas. The ability of spatial texture based ASI image representation to characterize the ASI image is explored in content-based image retrieval and supervised classification experiments. The applications of these image processing and computer vision