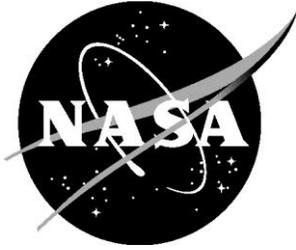


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Morphological Processing of Ultraviolet Emissions of Electrical Corona Discharge for Analysis and Diagnostic Use

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December 2015

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Morphological processing of ultraviolet emissions of electrical corona discharge for analysis and diagnostic use

Abstract—Electron cascades from electrical discharge produce secondary emissions from atmospheric plasma in the ultraviolet band. For a single point of discharge, these emissions exhibit a stereotypical discharge morphology, with latent information about the discharge location. Morphological processing can uncover the location and therefore can have diagnostic utility.

Index Terms-- Ultraviolet; Optical sensing and sensors; Image processing; Industrial inspection

INTRODUCTION

In electrical power transmission, great care is taken to avoid sharp protrusions on structures that are on or near high voltage conductors, to avoid a local concentration of the electric field that exceeds the threshold for coronal discharge. Electron avalanches from high-potential points produce, via impact ionization and subsequent recombination of atmospheric plasma, an ultraviolet (UV) photon spray. While most coronas are benign, some are indicative of a severe degradation that requires immediate attention; location, diagnosis and disposition of coronas is a necessary component of transmission line inspection. However, this method is applied infrequently due to the cost and difficulty of image capture (commonly in remote areas) and due to the cost of human inspection of UV-band imagery. More frequent inspection of power transmission infrastructure may be possible by low-cost aerial (UAV) image capture and automated image analysis.

PHYSICS OF CORONA FORMATION

The dielectric response to a high E field is a complex, multi-regime phenomenon [1], particularly when the field arises from an alternating (e.g., 60 Hz) source: cathodal and anodal coronas initiate, propagate and extinguish in each positive and negative half-cycle of alternation [2]. This letter describes morphological processing that automates UV-band corona analysis in the static discharge regime [3] in which the dielectric is air (at standard temperature and pressure) and in which the field gradient is insufficient, for a fixed source-to-sink distance, to produce spark-over or conductive shorting, as these are the conditions for which corona is difficult to locate and analyze. Coronal ionization/recombination sites decrease monotonically with distance r from the initiation point; in a planar projection into the viewport of a UV imager, the photon distribution appears as a solid ball of emission in the nucleus and a speckled halo in the periphery [4].

IMAGE PROCESSING TO LOCATE THE CORONA SOURCE

Since the peripheral emission sites appear as blobs with an area much smaller than the center site, a simple erode-AND operation can extract the center [5]. However, in electrical inspection, visible-band imagery is needed to determine the corona cause, and the context of the corona is necessary. For example, adjacency to a high-voltage conductor, and surface conditions in the area surrounding the corona center are of critical diagnostic value; methods that remove information about the corona radius are of limited utility. In this paper we report two additional methods to determine the corona center, and a method to determine the entire extent of the corona emission image.

Center determination

The first center-finding method of this study uses temporal averaging to accomplish via the time domain an analog to spatial erosion method of [5]. We found that for common camera settings, averaging frames over 1 second of 30 fps video is sufficient to robustly lower the average intensity of peripheral emission sites, so that a blob test based on area and circularity followed by a persistence threshold θ removes all sites except the center, and uniquely identifies the center coordinates.

$$C(x, y) = \int_t \{Area[I(x, y)] > A_{min}\} > \theta \quad (1)$$

If the UV imager viewport is not stable, this method suffers from distortions, as image smearing over time expands and skews the time-integrated area.

The second center-finding method counts the number of maxima of image intensity after Gaussian blurring,

$$C(x, y) = \max_{x,y} [G_\sigma(x, y) \otimes I(x, y)] \quad (2)$$

increasing kernel width σ until the count stabilizes to one; that maximum is taken as the center of the corona. (A related center-finding method conditions the increase in σ on locational stability of maxima, but at low σ this method falsely reports maxima at each site of peripheral emission, if the corona nucleus is not in the field of view.)

Extent determination

Corona extent varies with the gain of the UV imager multichannel plate [4][6]. To diagnostically determine a discharge location, human inspectors commonly i) start with a relatively high gain to find discharge figures, ii) lower the gain to remove stray ambient emissions and, if a characteristic radial morphology is recognized, iii) center the camera view on the coronal nucleus and iv) lower the gain further until only the center is visible and take a snapshot in the visible band with the UV nucleus overlaid. This sequence is based on the broadly reliable assumption that the corona nucleus is coincident with the high E field initiation point of the discharge, and effectively pinpoints the center within a diagnostic context.

To derive a computational basis with which to mimic the third and fourth steps of this behavior, we create an intermediate representation of corona morphology by applying a series of difference of box (DoB) filters with increasing size d , centered at the corona nucleus (Fig. 1). In this representation, if the DoB is balanced and the UV image is binary, the shape of the DoB score through scale indicates discharge isolation and morphological coherence. The positive extent of the DoB (central green boxes in Fig. 1) is a suitable frame for a detail snapshot in the visible band, while the negative extent (outer red boxes in Fig. 1) frames the contextual snapshot and can be used to prompt an operator to zoom out to capture the full diagnostic context (Fig. 1c).

To handle multiple coronas in a frame, if the area in (1) or the value of the center intensity in (2) (after zeroing the pixel values of the positive portion of the DoB; green in Fig. 1) is above the value expected for a corona nucleus, we repeat the DoB extent determination (Figs. 1d, 1e).

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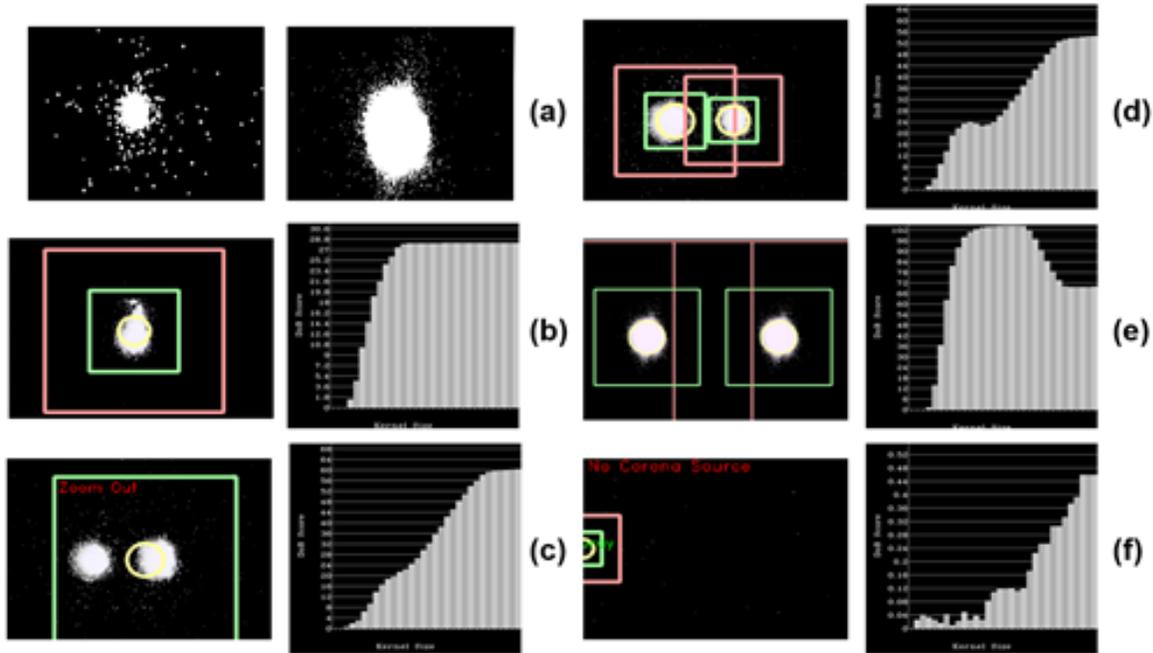


Figure 1 a) Two examples of UV corona discharge imagery captured at midrange camera gain. (b-f) DoB overlay of greyscale corona image (left) and scale space representation (right). If the score is monotonic increasing (b, c), or nearly so (d), a single visible-band image is sufficient to document the discharge. Well-separated coronas have a smooth but modal score through scale (e), while the score varies erratically through scale for ambient emission or peripheral corona spray (f).

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