Using 3D-Snake for Measuring the Length of Artificially Generated Electric Arcs

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Abstract—In this paper a new approach is proposed for the use of 3D-snakes in the evaluation of variations in the length of artificially generated electrical arcs. This active contour is geometrically represented by a B-spline and evolves in 3D space constrained by internal and external forces, it happens in an energy minimization procedure (“internal energy” and “external energy” is used in a sense related to visual images processing and not to physical energy related to the electrical arc behavior). This approach presents some important aspects in comparison with the ad hoc strategies found in the literature for recovering 3D geometry of electrical discharges. In addition, the proposal discussed in this paper is capable of tracking the evolution of the electrical discharge taking into account the time dependence between consecutive pairs of images.

Keywords: Electric Arc; Computer Vision; Image Processing.

I. INTRODUCTION

The major part of faults in Brazilian electrical system are single-phase and transitory which makes possible to apply the electrotechnical maneuver called Single-Phase Auto-Reclosure (SPAR) switching to normalize the system. Provided that such maneuver consists in opening just the faulty phase during a short time, minimizing the disturbance in the electrical system, the National Electrical Energy Regulatory Agency (ANEEL) has been recommended that new transmission lines must be capable to carry out such switching, since then a short electrical discharges recorded by a pair of cameras. This aspect is not presented in the strategies cited above, there are practically no restrictions on positioning of cameras. This aspect is not presented in the experiments reported in this paper is organized as follows. In the next Section (II) the 3D-snake model is discussed, in Section (III) a description of the experiment development and the approach applied on images of electrical discharges are given. Since the 3D-snake approach demands the knowledge of the projection matrices of the cameras, in Section (IV) is described the calibration procedure which provides these data. The results of the experiments are reported in Section (V) and the conclusions in Section (VI).

II. 3D-SNAKE

The 2D precursory model described in [9] is similar to the 3D-snake except that, in the latter model, the functional has external energies defined in 3D space and the external forces act upon the control points of a B-spline. The optimization of the functional constrains the 3D-snake to evolve itself in 3D space in order to match the difference is that 3D-snake extracts its external energy from more than one image, so that the external force must be composed in 3D from a stereo pair of images. In [10] it is already described initial experiments in which 3D-snakes are applied as a model of the axis of short electrical discharges recorded by a pair of cameras.

The remainder of this paper is organized as follows. In the next Section (II) the 3D-snake model is discussed, in Section (III) a description of the experiment development and the approach applied on images of electrical discharges are given. Since the 3D-snake approach demands the knowledge of the projection matrices of the cameras, in Section (IV) is described the calibration procedure which provides these data. The results of the experiments are reported in Section (V) and the conclusions in Section (VI).
this work) as vector maps, these are the final sources of external forces.

A. The functional of energy

Given (1), where \( Q \) represents a point generated by the B-spline through the set of control points \( V \) and the matrix of basis functions \( N \), the adjustment of the 3D-snake is defined by the functional shown in (2), where \( E(Q) \) defines the total energy of the system, \( E_{\text{int}} \) represents the internal energy component which preserves smoothness, at the same time that \( E_{\text{ext}} \) (external energy component) is responsible for the forces that attract the 3D-snake, pushing it into the features of interest captured in the images. This balance of energies must be optimized in order to the system gets a minimum of total energy and this procedure is done by the relaxation shown in (3) under constraints of internal and external forces [11].

Least squares are used for determination of the first set of control points over a set of 3D points obtained from the first pair of images [10], after that a new set of control points is obtained and so on, from one set to the other the 3D-snake is moved. Equation (3) represents such repetition, where the set \( V_t \) is calculated based on the old set embedded in \( F_{\text{ext}}^{cp} \) as shown in (4).

\[
Q = NV \tag{1}
\]

\[
E(Q) = \int_0^1 E_{\text{int}}(Q) + E_{\text{ext}}(Q) \, ds \tag{2}
\]

\[
V_t = (H + \gamma I)^{-1} \left( F_{\text{ext}}^{cp} - 3D \right) \tag{3}
\]

\[
F_{\text{ext}}^{cp} - 3D = \gamma N_t^{-1} - g(Q_{f - 1}) \tag{4}
\]

B. Obtaining the external force in the space of control points

In (3), \( F_{\text{ext}}^{cp} - 3D \) corresponds to the vector of 3D external forces in the space of control points and capable to act upon them for guiding the 3D-snake to adjust its projections in accordance to the current pair of images. To obtain such vector firstly is necessary to compose the ordinary vector of 3D external forces \( (F_{\text{ext}}^{3D}) \) from the pair of current vector maps and transform these forces to space of control points giving \( F_{\text{ext}}^{cp} - 3D \) in demand. This process is described next.

Considering Fig. 1, the point \( E \) (obtained by (1)) has the points \( E_1 \) and \( E_2 \) as its projections upon the pair of current vector maps. Assuming that \( F_{\text{ext}}^{2D} (E1) \) is the image force associated to \( E_1 \) by the vector map number 1 and the same for \( F_{\text{ext}}^{2D} (E2) \) about the vector map number 2, then the points \( F_1 \) and \( F_2 \) are homologous points and, this way, the retroprojection [12] of them gives the point \( F \). The vector \( EF \) corresponds to the wanted \( F_{\text{ext}}^{3D} \), this one is transformed to the space of control points by (5) [11] and the vector \( Vg(Q) \) corresponds one 3D external force that acts upon the control points. The vector \( F_{\text{ext}}^{cp} - 3D \) represents the set of all 3D external forces in the space of control points.
Then, this map of distances is operated by the gradient originating the vector map associated to its respective image. Each vector map is responsible for external forces, such as, $F_{\text{ext-2D}}(E_1)$ and $F_{\text{ext-2D}}(E_2)$ in Fig. 1.

**B. Automatic initialization**

The electrical arc is generated along the fuse wire and it resembles a straight line linking two points (the ends of the insulator string). At this initial moment the medial-axes of the discharge can be understood as a 3D vector whose extremities are points A and B. Fortunately, this vector AB can be recovered by triangulation of two pairs of homologous points projected at the pair of images taken. This is not a hard problem considering that the projections of the arc look like straight lines too. So that, it is a simple task to detect the extremities of such projections and triangulate them by retroprojection [12] in order to get A and B and the equation of the wanted vector AB. With such equation is generate a set C of points, so that these points constitutes the reconstructed electrical discharge in 3D at its initial instants of existence. The points in the set C are approximated by a third order B-spline ($B_0$) the first spatial representation of the 3D-snake.

**C. 3D-snake adjustment and measurement**

The 3D-snake evolves itself according to the minimization of its total energy functional described in (3). The snake converges to a stable configuration when a minimum of energy has been obtained which means that the evolution should stop because equilibrium of the internal and external forces has been reached. The goal here is a tracking operation, so the snake needs to find the equilibrium for each pair of vector maps available.

Being a model for the actual media-axes of the discharge, the 3D-snake should track it and the lengths can be estimated by measuring the B-spline contained in the 3D-snake model. The points of the B-spline should be generated by DeBoor's algorithm [14] and the sum of the Euclidean distance between two adjacent points gives the measure of the length.

Because the actual three-dimensional medial-axes representing the electrical discharge is unknown, the accuracy of this tracking must be evaluated by calculating how much each projection of the 3D-snake is adjusted to respective image of the current pair of images. For this sake the B-spline embedded in the 3D-snake model is projected upon the current pair of maps of distances. Each map provides a vector with the distances between the projection and the respective medial-axes that characterizes the image of a discharge. Then, these pair of vectors is concatenated in one big vector of which norm is calculated providing the measure of the adjustment wanted.

**IV. Calibrating the cameras**

The 3D-snake model demands knowledge of the projection matrices of the pair of cameras. Considering the tower and the coordinates of a set of 3D points (marks) determined in its structure, for calibration of each camera, an image depicting at least seven of these points must be captured, after that each projection is

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**Figure 1.** The image forces $F_{\text{ext-2D}}$ represented in vector maps are used for recovering the external force $F_{\text{ext-2D}}$ which is converted by $\theta^{-1}$ to the space of control points.

**Figure 2.** Image of a recent generated electrical arc and its histogram. The brightest pixels corresponds to the arc.
manually identified by inspection upon the image (automatic methods are not efficient in this case because of the latticework complex structure of the tower). The correspondence between each 3D point and its respective projection gives a projection equation system which solution is the wanted projection matrix. Algorithms such as the one described in [15] can be applied for determination of the projection matrix.

V. RESULTS

There is no way to get the actual length of an electrical arc, however according to [1],[2] and [3] the voltage between arc terminals per unit length is almost constant in a long arc such as the arcs analyzed here. This means that the effective first pseudo harmonic order arc voltage, \( V_{1rms} \), can be considered roughly proportional to the arc length, therefore, apart a scale factor, the curve representing the lengths of the arc via 3D reconstruction (3D-snake) has a profile similar to the curve \( V_{1rms} \) and this feature can be used for analysis. For the two experiments, both curves are plotted in the same axis where axis (OY) presents length in meters and \( V_{1rms} \) in kilovolts. Although it is impossible to compare meters with kilovolts, a similar profile were noticed between both curves, as can be seen, e.g., at Fig. 3 presenting the results of experiment number 1906. The lengths of the discharges measured by 3D-snake method rise from four meters (the length of the insulator string where the arcs started) to four times this initial length which is a consistent behavior, since the wind and the convection heat force the plasma to elongate.

VI. CONCLUSIONS

Since Brazilian national power system presents a natural scenario for SPAR usage, after year 2000 the regulatory agency (ANEEL) imposed the SPAR procedure for every new line project, specific studies became a national concern, a mathematical model of the electrical arc has been pursued since then and the variation of the length of the arc has been considered an important parameter. The present paper describes an innovative application of 3D-snakes that can be used for tracking, modeling and measuring the length of an electrical discharge.

Although the system acquisition was far from ideal, the results obtained show the potential of the strategy proposed and demonstrate advantages upon the traditional methods found in literature. New results will be presented soon with faster and synchronized cameras.

ACKNOWLEDGMENT

The authors thank support received from FURNAS, ANEEL, UDESC, COPPE/UFRJ, CEPEL, FAPESP (The State of São Paulo Research), from CNPq (The National Council for Scientific and Technological Development) and from CAPES (Coordination of Improvement of Higher Level Education Personnel).

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