Cross-arms Identification with Adaptive Digital Image Processing

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ABSTRACT
This paper presents an adaptive digital image processing algorithm to improve the identification and classification process of wood cross-arms in the context of automated image inspection robot for distribution power lines. Processing of images that come from outdoor environment is a very difficult task due to the interference of variation of lightning conditions, especially over non uniform objects like wood cross-arms. Usual approaches take advantage of threshold and reference variation in accordance to the best condition to extract desired image object. The proposed adaptive algorithm is based on the Adaptive Digitized Straight Line Segments (ADSLS) that sum up the capability of dynamic change of image segmentation process like binarization and contour extraction. Proposed algorithm was tested on the identification and classification of different type of wood cross-arm with polyurethane protective treatment and results shown improvement in the image segmentation process.

Keywords
Adaptive Digital Image Processing, ADSLS

1. INTRODUCTION
The electric power system is complex and can be viewed as composed by many subsystems. Power distribution lines (also called primary distribution system) are an important part of such system, which comprises the delivery of electricity from distribution substations to distribution transformers and to final consumers. Auxiliary elements, such as the cross-arms, which compose overhead primary power distribution lines, suffer damage due to high exposition to environmental factors such as vegetation and severe weather conditions [1]. Also, high currents contribute to damage in a long term. When the auxiliary elements do not work as required, it may cause several problems, e.g. poor electricity quality, and at in the worst case, the interruption. It is well known that power outages can cause more economical losses than any other causes [2] due to the high dependence of electrical energy by our society. The problems related to power outages and the rising pressure from final consumers and regulatory agencies led the distribution utility companies to raise investments to solve the problems.

To minimize such problems and assure the reliability of electric energy, the inspection of power line elements is an important task. The current inspection methods used by distribution companies can be classified into two categories: visual and by contact. In such scenario, an automated visual inspection robot was proposed by [3], which include improvements related works such as robot movement over the power line, such as in loco visual inspection and autonomous guidance. The main task of the robot is to inspect the cross-arms, in order to verify its servicing state. Actual inspection system is composed by a High Definition (1080 x 1920 pixel) CCD camera, that capture images from the power line, and a embedded image processing system with an ARM A-7 core that runs the image processing algorithm. A sample of distribution power line captured image is shown in Figure 1. The image, took at University test bed premise, shows the cross-arm, wire and other electric devices in the middle.

Figure 1 - Sample image captured from inspection robot camera

The main difficult in the image-processing algorithm is the variation of cross-arms composition, affecting the performance of computer visual inspection.

The increasingly high cost of native wood and new environmental laws have contributed to the emergence of alternative materials for the production of mechanical supports for transmission and distribution lines [4]. Norway, for example, has been using laminated woods for over twenty years, first for cross-arms in distribution lines and later for all 66 kV and 134 kV transmission line structures [5]. In the early 1990´s, in the US, Union Electric (U.E.) also evaluated alternatives for solid wood products, whose prices have increased steadily over the last decade, particularly those of cross-arms. U.E. has found that laminated wood cross-arms can offer an economically feasible alternative at a cost equal to or lower than solid sawn cross-arms [6]. In this context, although laminated wood is an alternative material for Brazil, reforested *Eucalyptus citriodora*, which satisfy the strength, electrical and thermal requirements for solid sawn cross-arms [7], are also economically suitable, if it receives special protective surface treatment against fungi and microorganisms [8].

Given the different aspects of the aforementioned cross-arms, this paper presents an adaptive digital image-processing algorithm to allow inspection of cross-arms with identification of two kinds: reforested *Eucalyptus citriodora* without superficial treatment; and reforested *Eucalyptus citriodora* with a polyurethane protective treatment [8]. In the identification process, the algorithm defines a region of interest using techniques of preprocessing and image segmentation. The technique choice depends on the image conditions (brightness, contrast, shape and size), as well as on the cross-arms visual characteristics.

The paper is organized as follows. Section II discusses adaptive digital image processing and elucidates the proposed approach. Section III presents the algorithm results and discusses them. Finally, section IV concludes the work and provides insights of future research directions.

2. ADAPTIVE DIGITAL IMAGE PROCESSING

The usual algorithm for image processing includes steps herein adopted that follows the same principles of [9], which are represented in Figure 2. [9] presented an alternative to the traditional classification of internal defects of Baumann samples, making use of digital image processing. The authors removed noises with a threshold technique and segmented the resulting image to identify a common internal defect with a linear pattern.

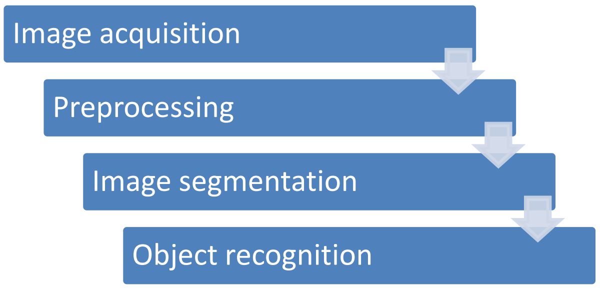

Figure 2 - General image processing steps.

In the Figure 2, the image acquisition phase receives the original image, acquired by devices such as cameras and stored in a database.

The image preprocessing has the purpose of improving the image quality. In this phase, image filters can be applied to reduce the image noise or to highlight object edges and contours.

The purpose of the image segmentation phase is to separate the image in different parts. This way, the object, or region, of interest, is extracted from the original image, to be, then, used in the recognition step.

Concerning image segmentation and object recognition, [10] presented a technique to identify moving objects in videos and, thereby, propose a new video compression algorithm. The authors achieved the desired results segmenting the images in blocks and conducting modular analyses to verify the blocks for moving objects. The same principle can be adopted in the herein studied case, in order to identify the cross-arms or to search it for undesirable fungi and microorganisms.

With the purpose of better identifying borders and, thus, segmenting the image or recognizing objects, [11] proposed an adaptive finite automaton to represent digitized line segments. In the digitalization process, it is inevitable that continuous line segments in Euclidean space be affected by distortion or corruption by noise generating digital line segments in string format with imperfections. Therefore, the adaptive finite automaton based algorithm is suitable to represent digitalized images, that includes errors, and also can help to identify line segments and object borders even in case of noise presence.

Another method of representing digital lines is based on continued fractions, studied by [12]. This mathematical approach provides appropriate models to evaluate errors and approximations in the digitalization process. After the work of [12], continued fractions have been researched, with several developments as described in [13].

Two main models were proposed to describe the pattern arrangement of Digital Straight Line Segments (DSLS) symbols. Taking into consideration the slope SL as the tangent of an Euclidean segment lying in the first octant, the models are given by the continued fraction of Expression 1.

$$SL = \frac{B}{A} = \frac{1}{P \pm \frac{1}{M \pm \frac{1}{K \pm \cdots}}} \qquad (1)$$

where the positive and negative signs are chosen to accelerate the convergence of the fraction and reducing the number of terms (indicative of the order of the model). Additionally, A, B (B H A), and P are positive integers, while M,K,… are not negative integer.

The model was denominated with first-order because slope SL was a first-order continued fraction. In the first-order model, the line segment traverses B rows and A columns with the slope SL = B/A = 1/P; where P, the first-order slope factor, is an integer. It means that A pixels of the line segment are uniformly distributed in B rows with P = A/B pixels in each row. For the first-order model, strings of DSLS are given by Expression 2 and shown by Fig. 4.

$$S_U : b^m a ; m \geq 1 \qquad (2)$$

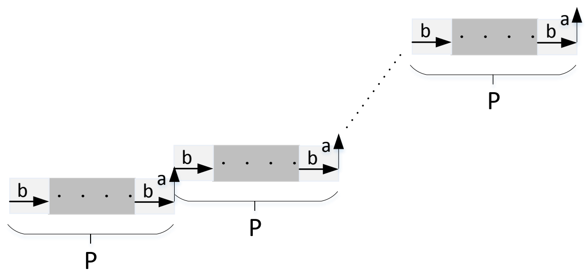

Figure 3 - First order model, characterized by constant P factor

In the second model, slope SL is a second order fraction SL = *B*÷*A* = 1÷[*P*±(1/*M*)]; and P is the nearest integer of *A* / *B* : *P* =[A / B]. This means that pixels are adjusted in each DSLS by placing *P* pixels in each of (*M* - 1) rows, with *Q* pixels in the remaining row; where Q can have only one of following two possibilities: *Q* = (*P*+1) or *Q* = (*P*–1). That is, the adjustment is made by decreasing *P* of a unit, or by increasing *P* of a unit. The row-by-row run-length representation of the line segment in the second order model can be expressed as *PQP*...*Q*.. shown in Figure 4.

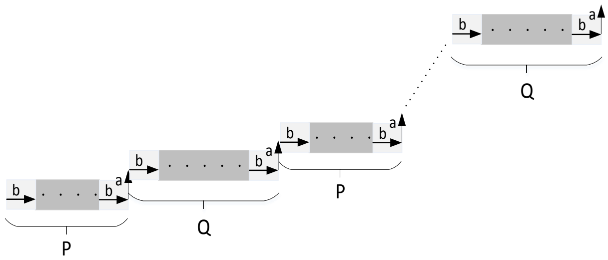

Figure 4 - Second order model, characterized by variation of P factor

In the second order model, strings of each DSLS may be of two types, as shown by Expression 3.

$$S_U: \begin{cases} b^m a.\ or; \\ b^{m+1}a; m \geq 1\ ou\ b^{m-1}a; m \geq 2 \end{cases} \quad (3)$$

In the second model, the main orientation angle, the one that stands out in the distribution of local angles related to the DSLS, is given by $\theta_S = \arctan(1/P)$ with slope $1/P$. However, DSLS occur with inclination $1/Q$ as spaced as possible. Thus, the orientation angle $\emptyset$ with the positive axis x of the continuous line that led to the codification will be in the range: $\emptyset \in [\arctan(1/(P+1)), \arctan(1/P)]$ (assuming $Q = P+1$) [14].

Essentially, angle errors of DSLS have a local behavior, as compared to the length analysis, which is more global, with a greater level of information regarding shapes. A digital arc S is understood as a set of interconnected pixels belonging to a digital image, positioned on a grid such that "each point of the set has exactly two neighbors, except two of these points, known as extremes, which have only one neighbor in S" [15]. Estimation of the length of digital segments is difficult and there being many length estimators [16]. As an introduction to this subject, [17] proposed the length of a segment codified by string: $S = s_1..s_i..s_n$ is given by Expression 4.

$$l_F = (v + h) + s(2)^{\frac{1}{2}} \quad (4)$$

With v, h and s as representatives of the number of vertical, horizontal and diagonal primitives in S, respectively. The mentioned length can only be approximated, requiring some correction factor ψ to adjust l_F equally to Expression 5.

$$l_E \approx \psi \times l_F \quad (5)$$

where l_E is the estimated length of S, after applying the correction factor.

Even an irregular arc may reveal itself as digitized straight-line segment, provided that it is reviewed in a compatible scale, using metrics. Thereby, adaptability can be an alternative to incorporate the fundamentals of arithmetic discrete geometry to the model of Freeman [17] and ensuring better results in image processing.

3. PROPOSED ALGORITHM, RESULTS AND DISCUSSION

The proposed adaptive cross-arms identification process was implemented using the OpenCV library for computer vision applications, with the programming language C++. The adaptive algorithm was included in the final phases of the original image processing algorithm implemented for the inspection robot.

Figure 5 shows sample of wood cross-arm segments with different level of polyurethane protective treatment that were used for testing proposed algorithm. In the figure, it can be seem the color difference between treatments and the influence of the wood texture in the reflected lighting.

Figure 5 - Original image of wood cross-arm segments.

In Figure 6, the original image was converted to grayscale in order to facilitate the image processing, because it has only one color channel.

Figure 6 - Grayscale image of wood cross-arm segments.

Figure 7 shows the blur filter application, which remove noises from the image. The Gaussian Blur uses a Gaussian function, represented by Equation 6, in a convolution process.

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2 + y^2}{2\sigma^2}} \quad (6)$$

In the equation, x is the distance of the horizontal axis, y is the distance of the vertical axis, and σ is the standard deviation of the Gaussian distribution.

Figure 7 - Image with Blur Gaussian processing.

Figure 8 shows the binarization process result of Figure 7, whose purpose is to find the contours region of interest. The threshold function, represented by Equation 7, is used to obtain a binary image that extracts the region of interest from a grayscale image.

$$dst(x,y)\left\{\begin{array}{ll} maxVal & if\ src(x,y) > thresh \\ 0 & otherwise \end{array}\right. \quad (7)$$

In the equation, *dst* is the output image, *src* is the input image, *tresh* is the threshold and *maxval* is the maximum value of the threshold.

Figure 8 - Controlled binarization process for extraction of the region of interest

Next phase uses the Canny function that makes a sequence of processing phases to detect borders: 1) Noise reduction with a Gaussian filter; 2) Intensity gradient and direction determination with the equations 8 and 9. 3) Irrelevant pixels removal; 4) Hysteresis, the Canny function uses the upper and lower limits to establish a rule.

$$G = \sqrt{G_x^2 + G_y^2} \quad (8)$$

$$\theta = arctan\left(\frac{G_y}{G_x}\right); \quad (9)$$

Figure 9 shows the contours found by the application of the original Canny function on the binarized image. In the figure, it can be seem that threshold and contour configuration in the Canny function can result in poor segmentation process with extraction of several region of interest.

Figure 9 – Extraction of region of interest with original Canny

The proposed extraction algorithm includes de second order DSLS with adaptive function depending of pixel intensity and desired segment length. If the intensity gradient of a pixel is higher than the upper limit, it is defined as border, whereas if the intensity gradient of a pixel is lower than the lower limit, it is discarded. If the intensity gradient of a pixel is between the limits, the pixel is defined as border with the condition of being connected to a pixel whose gradient is above the upper limit.

Figure 10 shows the results of segmentation/extraction process using the proposed algorithm.

Figure 10 – Contour extraction with proposed algorithm

Figure 11 shows the binarized mask used to recover the original image with the highlighted region of interest.

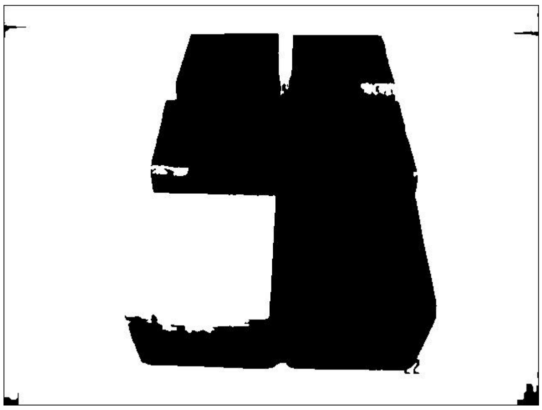

Figure 11 – Digital mask used to obtain the region of interest

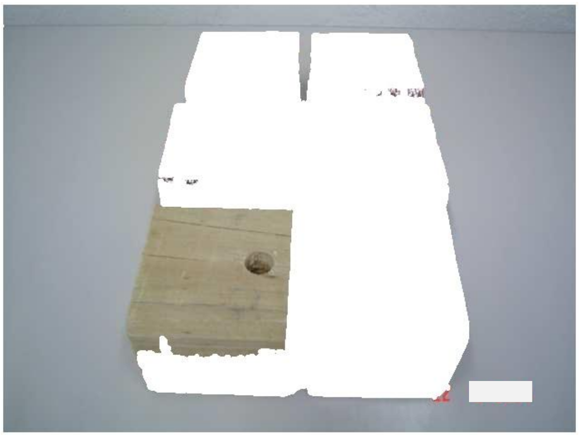

Figure 12 – Image with final result of adaptive segmentation/extraction process

Applying the mask shown in Figure 11 to the original image, it can be obtained the extraction of the region of interest, in this case, the wood cross-arm segment without polyurethane protective treatment, as shown in Figure 12.

If other cross-arm with polyurethane protective treatment must be identified, the inverse mask is applied, as shown in Figure 13.

Figure 13 – Sample image of identification of other region of interest

4. CONCLUSION

This work proposed a novel adaptive image processing algorithm to improve the identification and classification of objects in images with texture and lightning conditions variation. The algorithm was tested for identification of wood cross-arms types in the context of automated image inspection robot for distribution power lines. The original algorithm, before using the proposed algorithm, resulted in classification performance around 20%. The proposed algorithm was implemented in segmentation and contour extraction phases of image processing and test results shown that the classification rate was improved up to 70% of cases. Next step for conducting this work is to change the ADSLS used as basis of contour segment representation to improve the classification rate. In the ADSLS, each segment length and the number of segments used can be modified in accordance to the characteristics of the digital object to be found. The big challenge is to find a set of ADSLSs suitable to different kind of objects encountered in actual outdoor scenario.

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