Method for the identification of regions of interest of damage caused by the spine weevil (Cylindrocopturus biradiatus champs) on prickly pear (Opuntia ficus-indica)

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Abstract — **This article presents a method for accurately identifying damage caused by the prickly pear pest in nopal cultivation. The proposed method uses digital image processing techniques, including the convolution theorem through Fourier and Laplace transforms for image segmentation, obtaining the regions of interest. Strategies are employed to eliminate noise and improve identification accuracy. The results show a significant improvement compared to traditional approaches, suggesting an advancement in agricultural technology, specifically in the cultivation of cacti such as nopal. This study not only contributes to damage detection but also highlights its potential to improve decision-making in agriculture.**

Keywords - Image processing, Fourier transform, image segmentation, prickly pear cultivation, spin weevil pest.

I. INTRODUCTION(HEADING 1)

Digital image processing has become a fundamental tool with a wide range of applications in various fields. In this context, this article aims to address image segmentation with a focus on the agricultural sector, specifically in the area of prickly pear cactus (Opuntia ficus-indica) and the detection of cladodes damaged by the spine weevil pest (Cylindrocopturus biradiatus champs). The prickly pear cactus, as a commercial crop, holds great economic importance, as it is one of the few productive returns in semi-desert areas [1].

Its primary use is for the consumption of its fruit (prickly pear), whole cladode (pence), and chopped cladode (nopalitos), as well as its use as fodder for livestock. Additionally, it has industrial applications, producing alcohol, and from dyes to oils [2]. In Mexico, it is estimated that the cultivated area of the Opuntia genus prickly pear is approximately 13,618.3 hectares, with a national production of 864,243.5 tons in the year 2020 [3].

Early detection of pests and damage is crucial for the survival of the prickly pear cactus. One of the main pests affecting the Opuntia genus is the spine weevil (Cylindrocopturus biradiatus champs). When the larvae penetrate the areole, it turns yellow and exudes a brown, and later black, gummy liquid. By the end of the insect's biological cycle, the areole is completely dry and detaches from the cladode [4]. In digital image processing for pest recognition, efforts have been made to propose methods for detecting these pests and determining the actions to be taken within the crop [5].

The main objective of this algorithm is to develop a segmentation method based on direct and inverse Fourier transform, enabling precise and concise detection of damage count in the cladodes. The primary approach combines digital image processing techniques, mathematical treatment of matrices, and more accurate segmentations. Mathematical use of Fourier transforms, Gaussian blur for noise elimination, and various techniques for localizing regions of interest are employed. The Fourier transform is a mathematical tool used to transform signals in the time domain into functions defined in the frequency domain, where it is possible to analyze features that are not easily visible [6]. The Gaussian filter is used to blur images and eliminate noise. It is similar to the mean filter, but in this case, a Gaussian function is used to determine the kernel coefficients [7].

The main results show that the presented method achieves significant accuracy compared to traditional models. This study not only represents a significant technological advancement but also highlights the use of such techniques in agriculture and the cultivation of cacti like the prickly pear, a plant that survives in adverse environments but is also affected by pests. The use of technology will improve crop management decision-making.

II. BACKGROUND A RELATED WORK

A. Basic concepts of Digital Image Processing

Digital Image Processing: This refers to the processing of signals, which involves capturing photographs or parts of videos and subjecting them to various techniques in order to extract or search for features and data of interest, either to process these features or to obtain new processed images [8]. It is used in various applications in industry, medicine, biometrics, and identification in fields such as agriculture, livestock, and satellites, among others [9].

Digital Image: A digital image is a two-dimensional representation that is based on a binary matrix (ones and zeros). This depends on the resolution of the image, whether static or dynamic, which can be a raster image (bitmap) or vector graphics [10].

Pixel: A digital image is composed of a finite number of elements, each with a specific location and value. These elements are called image elements or pixels, with the latter being the most commonly used term [11].

B. Digital Image Processing Techniques

Grayscale Image Conversion: This conversion generates a single-channel image with pixels represented by a single 8-bit value ranging from 0 to 255 [11].

Resizing: Resizing an image involves expanding or contracting it in the vertical, horizontal, or both directions based on its axes [11].

Convolution Theorem: Convolution is a mathematical operation that combines two functions by describing a superposition between them. Convolution takes two functions, slides one over the other, multiplies the values of the functions at all points of overlap, and sums the products to create a new function. Convolution is an integral that expresses the amount of overlap of one function over another and is represented as follows:

$$(f * g)(t) \approx^{def} \int_{-\infty}^{\infty} f(\tau)g(t-\tau)dr \; [8]$$

Therefore, the functions can be replaced with signals, images, or other types of data. In image processing, convolutional filtering can be used for algorithms such as edge detection, sharpening, and image blurring [8]. In this case, following the corresponding theorem, the Fourier transform is applied, then multiplied by the high-pass filter function, and finally, the inverse transform is applied to convert the function back to the spatial domain using the inverse Fourier transform.

The Fourier transform is a mathematical transformation used to convert signals between the time or space domain and the frequency domain [9].

$$F(\xi) = \frac{1}{2\pi} \int_{-\infty}^{\infty} f(x)e^{i\,\xi\,x}dx \; [9]$$

The Fourier transform of a digital image is represented as:

$$\varphi(r,s) = \sum_{i=0}^{k-1}\sum_{j=0}^{k-1} \varphi(i,j)e^{-\frac{i2\pi(ir-js)}{k}} \; [8]$$

Where r and s are spatial frequencies, *i* and *j* are the rows and columns of the original image with dimensions *k x k*.

For grayscale digital images I(x,y), the Fourier transform is extended to two-dimensional functions and is calculated as:

$$I_T(u,v) = F(I,u,v) = \frac{1}{MN}\sum_{X=0}^{M-1}\sum_{Y=0}^{N-1} I(x,y)e^{-\imath\frac{2\pi xu}{M}}e^{\imath\frac{2\pi yv}{N}} \; [12]$$

And the inverse by:

$$I(x,y) = F^{-1}(I_c,x,y) = \frac{1}{MN}\sum_{X=0}^{M-1}\sum_{Y=0}^{N-1} I_T(u,v)e^{-\imath\frac{2\pi xu}{M}}e^{\imath\frac{2\pi yv}{N}} \; [12]$$

High-pass Filter: Operates in a way that attenuates low frequencies while leaving high frequencies unchanged. In images, high frequencies correspond to abrupt changes in density. This filter zeros out the Fourier coefficients related to low frequencies, leaving the high frequencies unmodified [8], thereby enhancing edge detection.

Gaussian Blur: It is a filter used to remove noise from images, which employs its own function to determine the coefficients of the kernel [13].

$$G(x,y) = \frac{1}{2\pi\sigma^2}e^{\frac{-(x^2+y^2)}{2\sigma^2}} \; [7]$$

Smoothing is controlled by the value of sigma, and this filter can be separated into two one-dimensional filters, which can be applied twice horizontally and vertically, making it more efficient.

Laplace Transform: The Laplace transform of *f is* defined as the function *F(s)* given by the integral:

$$F(s) = \int_0^{\infty} e^{-sx} f(x) = \lim_{b\to\infty}\int_0^b e^{-sx}f(x)dx \; [14]$$

The function *f* is called the inverse Laplace transform of *F*. The function *F* is usually represented by the symbol *L[f]* and is often written *as F(s)=L[f(x)].* Similarly, the function f is commonly represented by the symbol *L−1[F],* written as *f(x)=L−1[F(s)]* [14].

The combined use of the Laplace transform and the convolution theorem allows for more efficient and effective manipulation of images in the transformed domain, facilitating tasks such as filtering, segmentation, and noise elimination. This is crucial for advanced image processing in various applications, including precision agriculture, where it is used to enhance image features.

Canny Algorithm: It is based on the use of the first derivative, which takes a value of zero in regions where intensity does not vary and a constant value where there is a transition in intensity. Therefore, an intensity change can be seen as a sharp change in the first derivative, which is used to detect edges. The Canny algorithm uses gradient values, non-maximum suppression, and threshold hysteresis [15].

Shi-Tomasi Algorithm: It is a modification of the Harris corner detection algorithm, which has a corner selection criterion based on a score calculated for each pixel. If the score of a pixel is above a certain value, the pixel is marked as a corner. In the modification, the function to calculate pixel scores is eliminated, exposing the fact that it is only necessary to use the eigenvalues to check if the pixel is a corner [16].

$$R = \min\,(\lambda_{1,}\lambda_2)[16]$$

III. MATHERIALS AND METHODS

For this study, images of damaged nopal pads during the winter season were taken from a plot at INIFAP. The images were captured with a cell phone equipped with a 50-megapixel camera. This work is based on a methodology for visualizing regions of interest, starting with initial preprocessing that converts the images to grayscale, resizes them, and removes noise.

The next step is to process the images using the convolution theorem, which allows highlighting the features of the image and counting them. The employed methodology includes a combination of the convolution theorem with the Shi-Tomasi algorithm to enhance image features.

To implement this methodology, Python 3.10 was used along with the libraries Numpy, Pillow, Matplotlib, and the OpenCV 4.7 framework. First, the direct Fourier Transform was applied to transform the image from the spatial domain to the frequency domain, allowing the application of a high-pass filter that eliminates low frequencies without modifying the high ones. This is achieved by setting the Fourier coefficients of low frequencies to zero and then transforming the function back to the spatial domain with the inverse Fourier Transform.

Subsequently, the image is processed using the convolution theorem with the Laplace transform, applying a mask to further enhance the features. Finally, the image is processed with the Shi-Tomasi algorithm or the Canny edge detector algorithm, which allows the identification of relevant points in the image.

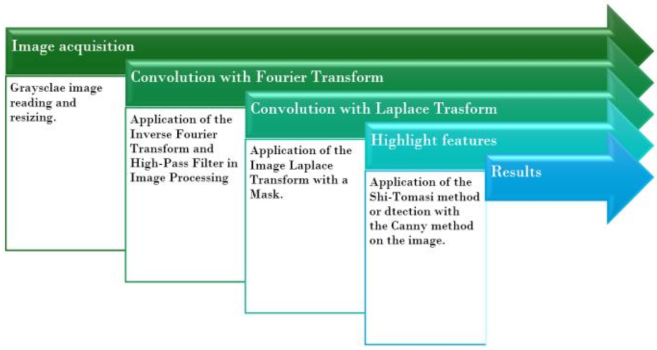

Figure 1. Processing algorithm for Highlight features

IV. RESSULTS AND DISCUSSION

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As a result of acquiring the 50MP RGB image, the initial test image is captured as a photograph and stored in a 3x3 matrix representing the RGB combination. Various areas of interest have been identified, showing damage caused by the agave weevil pest on the leaves.

Figure 2. Thorn weevil damage image

Within the application of the convolution theorem, the Fourier transform is applied, allowing for image compression and the application of the high-pass filter with the inverse Fourier transform.

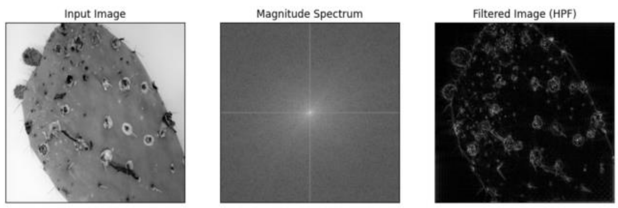

Figure 3. Image on frequency domain Fourier spectrum and image recovered from the high-pass filter process and inverse Fourier transform.

For the application of functions to evaluate points of interest, two were assessed: the Shi-Tomasi algorithm and the Canny methodology, yielding various results.

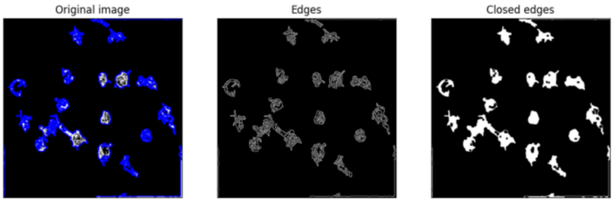

Figure 4. Image processed with Canny edge detector.

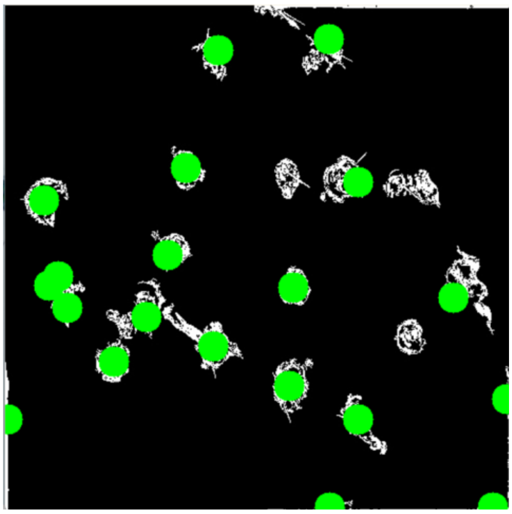

Figure 5. The image was processed using the Shi-Tomasi method, and points of interest were created using the K-means algorithm

DISCUSSION

The results of the study, when processing an image using the convolution theorem, show that the grayscale image highlights the areas of interest with greater visibility, in this case, the damage caused by the prickly pear pest. Both methods yield significant results, as shown below:

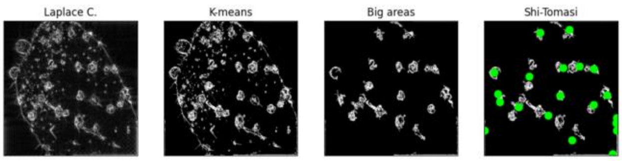

Figure 6.Detection of points of interest with the Shi-Tomasi method.

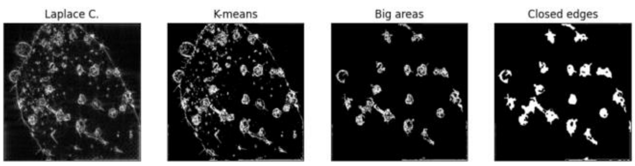

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Figure 7. Detection of points of interest with the Canny method.

The K-means algorithm counts all evaluated points and assesses centroids to group nearby points together, thereby making damaged areas more visibly prominent. When evaluating a color image with damage using this algorithm, it identifies the most damaged visible points and executes six processes in a single step.

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V. CONCLUSIONS

The evaluation of an image using the convolution method with Fourier Transforms and a high-pass filter algorithm significantly enhances our ability to extract the most important features from a region. This method stands out for its speed and efficiency when working with large images. Subsequently, various methodologies can be employed to assess the localization of these specific areas. This approach represents a promising perspective for the future of agriculture, offering systems capable of evaluating and monitoring crops for damage or pests. Advances in areas such as robotics, artificial intelligence, and computer vision open new opportunities to develop more precise and efficient systems.

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