Segmentation of the primary vein in leaves of Dioscoreaceae in specimens from Herbario Nacional Colombiano using computer vision

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Abstract—**In the leaves, primary vein structure and morphological features are relevant for taxonomy and botanical research. Extracting those features may be intensive labor for botanical experts, so an automated system to do so from images of the leaves would be a useful research tool. The first step towards that system is a segmentation model for the primary veins and contour of the leaves. A system based on a previous vein segmentation model is developed to segment the primary veins in Dioscoreaceae specimens from digitized herbarium collections. Another system is developed for segmentation of the contour based on a previous prompt semantic segmentation system. The results on the contour segmentation are sufficient to perform morphometric measurements on the leaves; however, the primary vein segmentation system may serve as a baseline model for other model proposals.**

Index Terms—**Dioscoreaceae, herbarium, segmentation, primary veins, morphometry, computer vision**

I. Introduction

Image-based plant phenotyping is a method used by biologists to characterize and categorize plants using image data. The process involves measuring information from individual or groups of plant samples in various environments such as greenhouses, fields, natural settings, or digitized herbarium collections.

An herbarium is a collection of dried plant specimens along with associated collection data. The specimens in a herbarium are typically used for two main purposes: describing and classifying the diverse range of plants, for which they play a crucial role in systematic and taxonomic studies, and they are also utilized by botanical experts to identify natural specimens in comparison to reference plant samples. This is an essential function for researchers working with plant identification [1].

Recently, many herbarium collections have been digitized, allowing new phenotyping studies to be performed [2]. A fundamental task in these studies is to identify and segment the biological structures in a given sample [2]. In particular, segmentation of the veins in the leaves has garnered attention [2], as well as detection and bounding of the different organs [3]. Leaves are organs with a crucial role in plant growth and biomass production, as sunlight absorption and carbon fixation occur within the leaves [2]. Therefore, leaf and vein morphometry are central in research involving crops and plants for human consumption.

Dioscoreaceae is a family of plants that includes the genus Dioscorea, known as yams. The term ”Yam” specifically refers to various species within this genus. The Dioscorea genus comprises over 600 species distributed globally across Africa, Asia, Latin America, the Caribbean, and Oceania. Approximately 10 of these species have been domesticated for food and income generation [4]. Yam has played a significant role in the food security, medicine, and economy of developing countries, particularly in West Africa, where it is the second most essential root and tuber crop [4]. In Colombia, yam cultivation is concentrated in the Caribbean region and has emerged as a vital component of the local diet. By 2010, Colombia ranked among the top 12 countries globally in yam production, securing the first position in terms of yields per hectare [5].

Veins in leaves have many characteristics, including classification as primary, secondary, tertiary, etc. A vein is said to be primary if it has the largest gauge and runs from the base of the leaf to the apex [6]. Veins of higher order branch from primary veins and have a lesser gauge. In the Dioscorea genus, leaves commonly present more than one primary vein, coming in pairs around the central primary vein.

Morphometrical features of the primary veins are of interest for taxonomy characterization, and some of the most important ones are the number of primary veins and their curvature. Other features of the leaves that have biological relevance for researchers are the area of the leaf lamina and the width of the leaf (longest perpendicular line to the central primary vein). With this in mind, the purpose of the present study is to produce an automatic system for measurement of the aforementioned features on primary veins in Dioscorea leaves preserved in herbarium specimens.

The most successful techniques in computer vision for the purpose of leaf image analysis predominantly include the use of Convolutional Neural Networks (CNN). CNNs have been widely used recently in computer vision and image processing as they have shown good generalization properties in tasks such as object detection and semantic segmentation. Usually, these models require large amounts of labeled data for training; however, many alternatives have emerged to solve this problem, like data augmentation and fine-tuning on pretrained models [2].

In this work, we use CNN-based models previously trained and made publicly available online.

II. Materials and Methods

The images used were taken from the digitized collection of the Herbario Nacional at Universidad Nacional de Colombia and the collection of the William & Lynda Steere Herbarium of the New York Botanical Garden, made publicly available online. Annotation of the dataset was performed on the online platform cvat.ai, following an annotation protocol approved by a Dioscorea expert. Both the contour and the primary veins were annotated as binary masks. Cropping out the leaves from each specimen image was performed by hand, selecting only the leaves whose dorsal side was visible and those which were not damaged or occluded by tapes.

For the segmentation task, there are a few relevant performance measurements, such as Jaccard index, Dice index, and pixel precision. Since the vein segmentation task involves a large class imbalance, we don't use pixel precision, for this measurement does not perform well on such cases.

Let G be the ground-truth mask, and M the prediction, then, the Jaccard index is defined as

$$\frac{|G \cap M|}{|G \cup M|}$$

And the Dice index is defined as

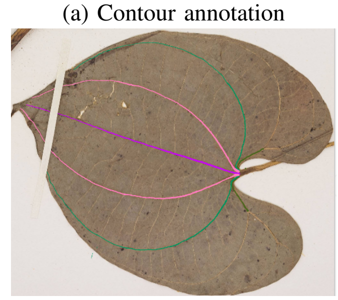
$$\frac{2|G \cap M|}{|G| + |M|}$$

The model used for the contour segmentation task is a general semantic segmentation model called Segment-Anything-Model, developed by the company Meta [7]. It is inspired by the feature of natural language processing models of taking ambiguous prompts as inputs and being able to produce a meaningful response as output. In the case of image semantic segmentation, an ambiguous prompt is a point on the object or a box around it, and the meaningful response is a segmentation of the object. For automatic segmentation, a sample of uniformly distributed points over the image is taken as an input, in such a way that all the objects in the image are segmented [7].

To find the contour among all the masks generated for a leaf image, the following procedure was followed: since the leaves were cropped as tightly as possible, leaving only a small gap between the contour and the edge of the image, thus the largest area mask is the contour. Since some leaves have lobes and indentations that increase the background area in the image, making the background the largest area mask in some images, an additional constraint to search among the masks whose intersection with the edge was less than 10% of the edge was placed.

The vein segmentation model used here [2] is based on a region growing network, which takes as an input a set of points (seeds) gives them a probability of being a vein or lamina and does the same to their neighbors. Then, it takes the newly classified pixels as seeds and repeats the process until the pixels are exhausted. The probabilities are then thresholded to give a binary mask of all the veins in the leaf [2].

(a) Contour annotation



(b) Primary vein annotation

Fig. 1: Examples of the annotations on a leaf from a Dioscoreaceae herbarium specimen

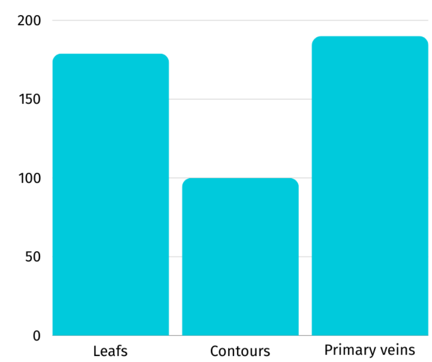


Fig. 2: The number of labels produced for each class.

III. Results

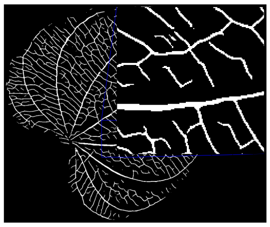
The annotation protocol required each primary vein to be classified according to its position relative to the principal primary vein, i.e. the vein at the center that separates the leaf into two symmetrical parts. The nearest primary veins to the principal vein are labeled L1, the next are labeled L2, and so forth. An example of the annotations of the contour and the primary veins is shown in Figure 1.

A total of 469 masks were produced, as shown in Figure 2.

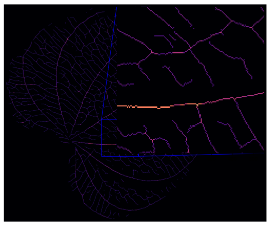
The values of Jaccard index and Dice index obtained for the contour segmentation task and the primary veins segmentation task are shown in Table I.

	Jaccard Index	Dice Index
Contour Segmentation	0.9	0.85
Primary Vein Segmentation	0.34	0.0001

TABLE I: Performance measurements for the produced models

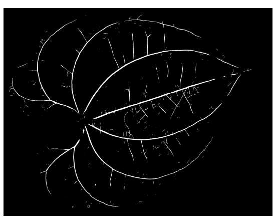


(a) Veins mask produced by the model from [2]

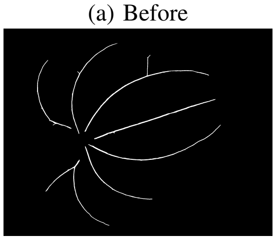


(b) Skeleton in color map

Fig. 3: Vein segmentation mask and skeleton produced from it. Each pixel value in the skeleton is the distance from the pixel to the closest background pixel on the original mask



(a) Before



(b) After

Fig. 4: A vein segmentation mask before and after post-processing to extract only the primary veins

Finding the primary veins required a post-processing of the masks. To do so, a skeleton of the veins mask was produced using the medial axis transform [8], with the height of the image as the distance from the edge of the vein to the medial axis, that is, an approximation of the width of the vein at each point. An example of the skeleton produced is presented in Figure 3.

Since the primary veins are generally wider than the higher order veins, the segments with a width of one standard deviation over the mean were considered primary veins. After filtering the small residual structures, a mask of the primary veins was obtained. An example of a mask before and after post-processing is shown in Figure 4.

IV. Conclusions

The performance of the contour segmentation model is sufficient to allow morphometry on the contour of the leaf. On the other hand, the primary vein segmentation model may serve as a baseline model to compare for future developments. A better post-processing of the masks may improve the results, since a few segments of the primary veins (the thinnest ones) are eliminated. Further work on the morphometry over the primary veins can be done to find a suitable curvature measurement and a processing of the masks to isolate the different primary veins.

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