Macroscopic pest detection system for aromatic herbs in post-harvest stage using computer vision and neural networks techniques

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Abstract. Worldwide consumption of aromatic herbs has increased in recent years, which has led to an increase in the areas of cultivation and exports of these plants in producing countries. Within the production chain of these herbs, phytosanitary control is a requirement for the quality assurance and exports of the product. Pests cause damage in the plants, not only in the crop but also after the harvest. According to the regulatory authorities, who conduct inspections for pests, bad phytosanitary practices lead to the return of the product from the port to its origin or destruction in the country of destination. This results in an economic loss to the producer and exporter of the plant. One of the aromatic herbs with the highest level of production and export in Colombian market is thyme (Thymus). This work presents a support system for detecting macroscopic pests in thyme using computer vision techniques and neural networks. The main contribution of this work focuses on product classification between free and not free for pest in the postharvest process.

1. Introduction
Small and medium-sized crops, many of them in the informal sector, characterize the productive sector of aromatic, medicinal and spices plants (AMSP) in Colombia. Regulations, however, clearly contemplate the technical and quality requirements that AMSP crops must achieve to commercialize their products within the national territory or even outside it. The “Norma Técnica Colombiana (NTC) 5400 [1] standard, developed by the “Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC),” considers within the good agricultural practices (GAP) for culinary aromatic herbs and fresh herbs the following items: phytosanitary control of the crop within the principles of Integrated pest management (IPM) and integrated crop management (ICM) as long-term strategies for the protection of plants and thus ensure the safety of agricultural derivatives, productivity and sustainability of agricultural production. In addition, NTC 5522 [2] extends the concept of traceability as a GAP requirement, which allows producers, manufacturers and health authorities to follow a track of food from its origin until it reaches the national or international consumer. As a result of the implementation of a traceability system, it is expected that management change in the companies, by the incorporation of information management technologies, which allows the necessary documentation to be developed to demonstrate compliance with the demanded requirements [3,4].

Throughout the process of exporting AMSP plants, certification standards and destination markers are very strict so factors that may affect the quality of the product should be minimized. Among the
critical factors in the export process of aromatic plants is the detection of plagues after the harvest [3]. Customs facilities must return or destroy all products with presence of pests, resulting in economic losses for producers. In order to contribute to the supply of pest-free foods, which is very important in national and international markets and ensure compliance with GAP, a system for the detection of macroscopic pests in aromatic plants for the post-harvest stage is proposed. Many implementations of pest detection systems in crops have been reported in the literature. In [5] results of detection of whitefly in a paprika greenhouse located in Korea are reported. The system, equipped with a robotic arm and a web camera are capable of capturing the images of the leaves, it implements three different detection algorithms to reduce the noises present in a greenhouse (reflected light and complex textures). In [6], simple image processing strategies are used to detect pests in rice crops. This system is based on images taken in traps near plants and background subtraction methods. A previous work [7] presents a review of techniques commonly used in the automatic classification of insects in their different stages, however it presents results of recognition of different insect species using clustering techniques. The implemented system considers the conditions of the production chain of these plants, as well as the characterization of the main pests that affect them. Contribution of this work focuses on the use of computer vision techniques for processing of plant samples and separation of these, between free or not free of pests.

The article is organized as follows; the second section describes the different stages present in a pest detection system. In the third section, productive process of thyme and most common pests that affect it are characterized. The fourth section describes the implemented detection system. Finally, in sections five and six, results obtained and conclusions are presented, respectively.

2. Computer vision and artificial intelligence techniques for the pest classification

Computer vision techniques are widely used for detection of objects in various processes. These techniques are mainly based on the extraction of characteristics of the object to be detected, that is, color, shape, size, in addition to features related to the medium in which they are located as edges, distances, between others.

In Figure 1, stages of an object detection system are described. In the first stage, images must be acquired with the proper sensor (camera), which is selected according to requirements of the application. Characteristics to take into account to select the camera are mainly its resolution, field of vision, frames per second (fps) and its speed of processing. A similar process for insects detection and classification is described in [8].

![Figure 1. Object detection strategy.](image)

In second stage, all pre-processing techniques are performed. This stage is focus in reduction of noise and the enhancement of important details. In a pest detection system, this stage allows to isolate, through the thresholding and binarization of samples, plants with pests from the background. The third stage named segmentation facilitates the recognition and generation of regions of interest of objects detected in the samples for a further feature extraction.

These features must contain enough information for performing the identification stage. Finally, in identification or classification stage, designed based on a decision-making model, objects are categorized according to some predefined parameters and metrics. The structure of the classifier, as well as the techniques implemented for their design can vary according to the application and objects to be detected. In this application a robust classifier was required due to changes in the position and size of the pests. According to these requirements, a neural network was selected, to be trained with the characteristics extracted from some of the samples.
2.1. Neural networks as classifiers

Neural networks (NN) are computer-based systems that use interconnected processing units called neurons for data processing. According to its topology NN can address different problems such as modeling of nonlinear systems and data classification [9]. Thanks to the ability to learn, to be generalize and its easy implementation, the multi-Layer perceptron neural network (MLPNN) is one of the most used topologies. Inside the MLPNN framework, each neuron \( j \) of the hidden layer adds up its inputs after being multiplied by the corresponding weights \( W_{ij} \) to each connection. Output of a neuron \( j \) corresponds to Equation (1).

\[
Z_j = f(\sum_i W_{ij}X_i),
\]

where, \( f \) is the neuron activation function. This activation function can be represented by a sigmoid function, a linear function, a hyperbolic tangent or a radial basis function. In this study, a symmetric sigmoid function is used as the activation function for the neurons in the hidden layer neurons and a sigmoid function for the neurons in the output layer. The average error between the desired output (reference) and the current output is defined as Equation (2).

\[
E = \frac{1}{2} (Z_{do} - Z_o)^2,
\]

where, \( Z_{do} \) is the desired output and \( Z_o \) is the current output. Figure 2 shows topology of MLPNN with a single hidden layer and a single output.

![Figure 2. NN topology.](image)

The objective of training stage is modifying weights \( W_{ij} \) in such way that error \( E \) is minimized, therefore there are several types of training algorithms; one of them is the back propagation, which is selected in this study.

3. Characterization of the post-harvest stage in aromatic herbs

Aromatic plants are those that can generate, thanks to a physical-chemical process, an aromatic product, that is, a product with a specific smell or flavor [10]. According to The Ministry of Agriculture of Colombia, the aromatic productive sector is composed by approximately 400 varieties of plants, produced mainly in the states of Cundinamarca, Antioquia and Valle del Cauca. In Antioquia, the most relevant plants, according to exported quantities, are mint, basil, thyme, rosemary and tarragon, which are mainly cultivated in the east part of the department [11]. The typical post-harvest process of these plants is characterized by the following stages: Plant comes into post-harvest area in baskets; If it is necessary, broken stems and withered leaves are removed from each plant. A visual inspection is performed to look for residues and/or macroscopic pests; After the first visual inspection, plants must be shook to remove macroscopic pests and / or microscopic that it wasn’t detected before; Plants, with five pests, are removed. Then the remaining plants continue to the packing and storage stages. For particular case of thyme, shaking process is done by bouquets of approximately 30 plants, holding them vertically (stems at the bottom) and executing soft hits against the work table. If a bouquet has pests, it is expected that they fall over the table during the shaking process, but sometimes process is not effective, due to the size and fragility of the leaves, in addition density of bouquets can block the fall of all pests. The objective of proposed detection system is to improve the visual inspection and shaken
stages. After characterizing the productive chain of aromatic plants, it was also important to identify pests that commonly affect this kind of plants. The investigation showed that nematodes, cutters, slugs, white flies, snails, worms, among others are harmful insects [12,13]. Only a few of them was selected as samples for the detection system, according to the following criteria: Only macroscopic pests are selected, after several experiments, pests with the lowest probabilities of falling during shaking are selected. Due to its morphology some pests will be left inside the bouquets and availability of samples: During several visits to the crops, slugs were highly detected. In the following subsection, characterization of slugs is presented.

3.1. Slugs (Limaco)
They belong to the family of Gastropod mollusks, which usually have small internal shells and elongated and viscous bodies, brown or black. They have two pairs of tentacles in the head. Although it depends on the species, adults usually have 30 mm to 150 mm long. Eggs are usually oval and its size ranges between 2 mm and 4 mm long. For the characterization of this pest, imagines of some slugs were initially acquired. These images or samples were processed for extraction of special and unique characteristics. Figure 3(a), Figure 3(b), Figure 3(c), and Figure 3(d), show 4 of the 48 slugs selected as samples. First 35 × 33 pixels region of interest was set up. Subsequently, some morphological techniques such as erosion, elimination of small objects and dilation were performed. Binarization threshold was set up in 108, meaning that pixels with intensities higher and lower than this threshold are replaced with 255 and 0, respectively. Process of erosion and dilation were performed using a 3 × 3 square structuring element and in the elimination of small objects stage, only objects with areas higher than 10 pixels are kept. Three metrics, based on the histogram of pixels of the samples, were obtained after applying processing techniques. These are average, standard deviation, and area. The first two metrics are mainly used to describe normal distributions, but in this context provide information about the intensity of grays (indications of the color of the sample) and the third technique gives information about the size of the sample after binarization. Table 1 shows the selected metrics for the samples.

4. Implemented system
The first part of this section describes hardware and software elements that make up the system. The second part details stages used in the methodology proposed for detection of the characterized pest.
4.1. System components
The detection system is composed of the following elements: Monochrome camera with 640 × 480 pixels resolution, lighting system: White light and image processing software. The camera is located in a plane perpendicular to the samples. Its distance is adjustable so that its field of vision can completely contain the samples of plants with pests. The lighting system consists of a single white halogen light, located at the top of the system structure and perpendicular to the samples. During the implementation of detection system, different software tools were used. MATLAB training neural networks was performed, while in LABVIEW the other stages of identification system were implemented: capture, processing, segmentation, extraction of characteristics and identification.

4.2. Proposed methodology for pests detection
Detection of pests was divided into two stages. In the first stage it was used a pattern image and the average and standard deviation metrics for the recognition of possible pests present in the new images. The output of this stage were the regions of interest in which the greatest coincidence was obtained with the pattern and with the first two metrics of characterization of the pests. Pattern recognition is a method that introduces a descriptor that uses the shape of an object (to be detected) in a global way, in other words, it detects in the image, the window that most resembles the chosen pattern. The problem of detecting a pattern of objects with different scales is usually solved in two ways: The first and most used is the convolution in which different copies of the pattern, built at different scales and in an ascending way, are convolved with the image. The second strategy considers the convolution of a fixed-size pattern with different copies of the image at different resolutions. This last method is known as pyramid method and it turns out to be more efficient and less computationally cost than the convolution [14]. Lower level of the pyramid or level zero is equal to the original image. This is filtered and sampled by a factor of two to get to the next level. Subsequent filtering and sampling repetitions generate the remaining levels. According to the above, levels of the pyramid are obtained iteratively from the Equation (3).

$$G_l(i,j) = \sum_{m}^{n} \sum_{i}^{m} \omega(m, n)G_{l-1}(2i + m, 2j + n),$$  \hspace{1cm} (3)

where, \(\omega(m, n)\) are weighted Gaussian functions, \(G_l\) the current level and, \(G_{l-1}\) the previous level. The complexity of the patterns that can be found with this method is limited due to the fact that not all scales of the image are represented in the pyramid. When you have complex patterns, as in this case, a closer correspondence, between the scale of the selected pattern and the scale of the pattern, is required as it appears in the image and therefore the steps of powers of two by two may not be adequate. In this direction, different variants of the method are presented, aimed to define smaller steps and/or defining more levels in the pyramid. In this work, adding two criteria to determine whether or not there is correspondence with the pattern modifies the pattern recognition algorithm. This means, once the pyramid method is executed, average of the intensities of the pixels and standard deviation in the selected window are compared with the average and the standard deviation of the pattern, and determines which is the window or region of interest that has greater similarity. Figure 4(a) shows the pattern selected for recognition of slugs.

The second stage is composed of a double layer neuronal network with 15 neurons in the hidden layer with a symmetric sigmoid activation function. A neuron in the output layer with binarized sigmoid activation function. Its operation is as follows: input of the neural network is the value that corresponds to the counting of white pixels after processing that is executed in each one of the regions of interest delivered by the previous stage. The processing corresponds to a binarization and application of morphological techniques as described in section 3. The output of the neural network is 0 if this region of interest does not correspond to a pest and 1 if it corresponds. All number 1 generate a detection window that is overwritten on the captured image. Finally, we proceed to generate windows on correspondences thrown by the neural network or by the stage of pattern recognition modified the captured image. Figure 4(b) shows the methodology described above for the detection of slugs.
5. Analysis of results
Figure 5(a) and Figure 5(b) shows prototype built for acquisition of samples and for detection of pests. As mentioned in previous section, 48 samples were taken, which were characterized using three selected metrics. The performance of system was evaluated for three different scenarios: A first scenario with detection using only pattern recognition, to evaluate the performance of the first stage. A second scenario included generation of false positives to evaluate the performance of the first two stages, and finally, in a third scenario, a pest-free plant was analyzed to evaluate the performance of the system in general. The system initially captured images; it took approximately 7 seconds to process it completely and to determine whether or not there were pests. In the first scenario, modified pattern recognition strategy successfully detected the slug present in thyme. It can be observed that initially the pyramid method, Figure 6(a), by itself only leads to an accurate detection and several false positives. Then comparison with selected metrics allowed to reduce the number of false positives obtained initially, however, at the end of the processing it was not possible to individualize pest using only this technique, Figure 6(b).
In the second scenario, the first stage did not generate a single detection window so neural network went into operation. With the application of neural network, it was possible to reduce the amount of false positives generated in the first stage. Although it was not possible to eliminate all the false positives, neural network maintained the correct detection, Figure 6(c). The Figure 6(d) shows the Free of pests: Pyramid method. Finally, in the third scenario, in the two stages there was no recognition of pests, Figure 6(e) and Figure 6(f).

6. Conclusions
The results that were obtained are conditioned by hardware characteristics of the acquisition system implemented and by pest samples availability. According to this, the following two remarks are made: First, acquisition of monochromatic imagines is suitable for applications, where it is necessary to identify a predefined pattern (quality defects in a serial production). For applications that imply acquisition of objects or scenes with variable content, the monochromatic imagines do not provide enough information for performing a feature extraction. An improvement strategy includes image acquisition with a color camera. It would supply the system with further information for performing pre-processing stage and for extracting characteristics that increased reliability and performance of the system. Second, although detection of microscopic pests is out of the scope of this investigation, setup of cameras could be implemented. These cameras, with microscopic visual capabilities, would allow fractionating the image acquisition.

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