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Algorithm for Path Recognition in-between Tree Rows for Agricultural Wheeled-Mobile Robots

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Abstract**—**Machine vision has been widely used in recent years in agriculture, as a tool to promote the automation of processes and increase the levels of productivity. The aim of this work is the development of a path recognition algorithm based on image processing to guide a terrestrial robot in-between tree rows. The proposed algorithm was developed using the software MATLAB, and it uses several image processing operations, such as threshold detection, morphological erosion, histogram equalization and the Hough transform, to find edge lines along tree rows on an image and to create a path to be followed by a mobile robot. To develop the algorithm, a set of images of different types of orchards was used, which made possible the construction of a method capable of identifying paths between trees of different heights and aspects. The algorithm was evaluated using several images with different characteristics of quality and the results showed that the proposed method can successfully detect a path in different types of environments.

Keywords**—**Agricultural mobile robot, image processing, path recognition, Hough transform.

I. Introduction

MANY applications of machine vision have been proposed in recent years for use in agriculture, with the use of aerial or terrestrial unmanned vehicles to perform tasks such as quality grading of fruits, precision farming, fruit picking and process automation [1]. In this sense, machine vision allows for the evaluation of several characteristics, such as shape, size, color and location, representing these features as data that can be processed by a computer.

Wheeled-mobile robots have been widely used to perform agricultural specific tasks, such as automated irrigation with the aim of reducing water consumption [2], extensive inspection of crops [3], seeding [4], and harvesting [5], [6]. This scenario has created a field of study dedicated to explore and develop techniques regarding guidance systems that can be used to assist agricultural robots in different environments.

Several image processing techniques and operations are used to perform the extraction of features that can represent possible paths to be followed by a mobile robot. Authors usually employ operations such as threshold segmentation and morphological erosion to strengthen shapes that represent potential lines and to remove undesired information [7]. Different color space representation have also been extensively used in the literature, such as the Hue Saturation Value (HSV) color map, that can be used to evaluate the amount of noise on an image [8].

There are also multiple techniques to identify lines on an image, and then construct a path. One successfully used method employs the Hough transform [9] to search for possible lines on images by calculating the number of possible lines that cross a point of interest. The algorithm proposed in this work uses the aforementioned techniques alongside the Hough transform to extract a path on images of different types of environments. We also explore resources such as contrast limited adaptative histogram equalization and the Sobel operator, that will be described in the next sections.

While several works found in the literature use the Hough transform to find a center line [10], our method proposes the detection of parallel lines, from which the algorithm generates an equidistant line that will constitute the path to be followed. This approach gives us the liberty to generate lines in different locations, that can be used to fit the path according to the level of the terrain.

The reminder of this paper is organized as follows: Section II describes the proposed algorithm and the techniques used to perform image processing and to obtain the navigation path. Section III presents the experimental results. Section IV draws conclusions and possibilities for future work

II. The Proposed Algorithm

The development of the path algorithm extraction was performed using the software MATLAB, which provides an image processing toolbox with several functionalities that allow transformation in image space color representation, mathematical and morphological operations, etc. In this section, we first describe the image processing and next the mechanisms to create the path.

A. Color Space Representation

The first part of the algorithm consists in, after loading the image to be processed, converting it into a gray scale representation. In this representation, a colormap is generated which is composed of three columns and a number of rows equivalent to that of the original image [11]. Each row of this array contains the intensities of red, blue and green correspondent to colors of the original image and represented in the range [0,1]. In Fig. 1, it is possible to compare the original image with its representation in gray scale.

B. Feature Enhancements

The original image is also converted into the HSV color

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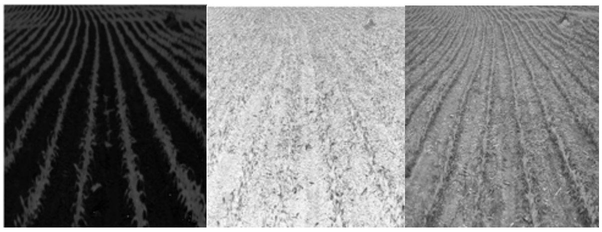
map. The goal of this transformation is to perform an evaluation of the levels of saturation in the original image and compare the results with an experimental determined standard to decide whether the image needs enhancements or not. Fig. 2 shows each component of the representation separately.

(a) (b)

Fig. 1 (a) Original image, (b) Gray scale representation



(a) (b) (c)

Fig. 2 (a) The image of H component, (b) the image of S component, (c) The image of V component

In case enhancements are needed, the gray image goes through two processes:

- The first enhancement adjusts the intensity values of the colormap by taking the gray scale image and saturating the bottom and top of all pixels in 1%, what increases the contrast of the image.
- The second enhancement employs contrast limited adaptative histogram equalization (CLAHE). In this technique, each pixel is enhanced according to a transformation function based on the histograms of the surrounding pixels but, differently from classical adaptative histogram equalization, CLAHE limits the contrast enhancement by cutting the histogram in a specific point, before computing the cumulative distribution function of the neighborhood, which is used to perform contrast enhancement [12].

Fig. 3 shows the results of the two enhancements.

C. Threshold Selection

In the next step of the processing, the algorithm applies a threshold selection based on the Otsu's method [13] with the goal of highlighting the desired shapes from the background of the image. This method relies on iterating through all possible thresholds in the gray scale image and choosing a threshold to minimize the variance between black and white inside an intraclass. Fig. 4 shows the result of the threshold selection operation.

(a) (b)

Fig. 3 (a) Intensity adjustment, (b) contrast limited adaptative histogram equalization

Fig. 4 Threshold selection applied to the image

D. Morphological Erosion

A morphological operation is next used to help identify and eliminate undesired elements in the remaining image. In this class of mathematical operations, each pixel in the image is considered as being a function of a subset of neighboring pixels in the input image. To perform this operation, a structuring element is first stablished, and the operation considers the shape of this structure to minimize the values of the surrounding pixels in a process known as morphological erosion [14]. The algorithm performs the minimization process with a symmetric circular element of radius 1, which was chosen experimentally, and the operation is executed twice. In Fig. 5, it is possible to see the image after the process of morphological erosion.

E. Edge Detection

After the morphological operation is completed, the algorithm uses the Sobel operator to perform edge detection [15]. This operator works by computing the gradient of the intensity function extracted from an input image and suppresses the noise in the image by defining a weight that grows in the direction of the central point of the mathematical representation, which allows for the identification of undesired information. Fig. 6 shows the result of using the Sobel operator.

F. Hough Transform

At the end of the recognition process, the Hough transform is applied to identify lines in the binary image. This transform considers lines in their parametric form, and uses the concept of Hough space, where lines are represented as a single point. A point inside the Hough space is mapped to all possible lines that can pass through it which generates sine-like representations of possibilities in the representational space, as observed in Fig. 7 that shows the Hough space applied to the binary image that has been used so far.

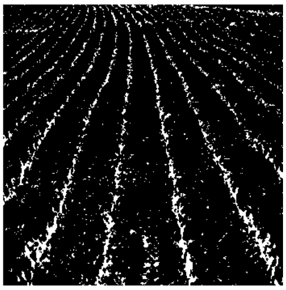


Fig. 5 Result of the morphological erosion

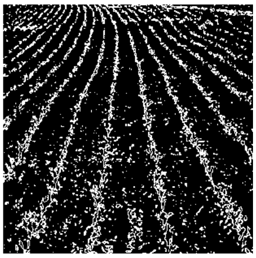


Fig. 6 Edge detection with the Sobel operator

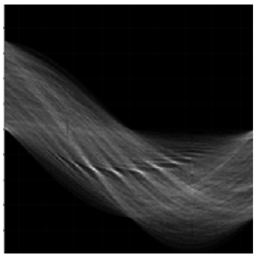


Fig. 7 Representation of possible lines in the Hough space

Fig. 8 Lines detected through the Hough transform

The transform then uses an accumulator to evaluate the points where lines intersect each other in the Hough space, and true lines are chosen considering the points with higher values in the accumulator. Fig. 8 shows the lines detected for the image in analyses. The red points at the bottom of the image are used to mark the beginning of the detected lines.

G. Obtaining Navigation Path

The lines obtained in the last step are used to create a navigation path between the rows. The basic idea here is to generate a center line that will be the line followed by the robot, and the starting point of this line is the median point between the beginning of the two lines. The final point of the path can be determined in two ways:

- If the detected lines intercept each other before the end of the rows, the final point of the navigation path will be the point of intersection of the parallel lines.
- If the lines do not intercept each other, the final point for the path line should be the median point between the points that mark the end of the two parallel lines.

Fig. 9 shows the navigation path obtained.

Fig. 9 Navigation path obtained

III. Results and Discussion

In order to evaluate the effectiveness of the proposed method, we first applied it to images of different orchards, with different features such as height of the trees, level of saturation on the image and different types of vegetation on the ground. We also explored the efficiency of the algorithm in finding the path in situations where the detected lines do not intersect each other. Fig. 10 shows the results obtained for two cases.

(a) (b)

Fig. 10 (a) Navigation path with intersection point, (b) navigation path without intersection point

As the application of enhancements to the original image is conditioned to its quality in the first place, it is of interest to know the time required for the algorithm to perform the path generation when enhancements are needed, in comparison with cases when enhancements are not performed. In that sense, Table I shows the average time required for processing in both situations.

TABLE I
AVERAGE TIME REQUIRED TO GENERATE THE PATH

Scenario	Time of image processing (ms)
Enhancements applied	55.58
No enhancements applied	88.85

Results in Table I show that, even though images that need enhancements are primarily less suitable to be processed, the use of operations to enhance certain characteristics make the process of lines recognition more efficient. On the other hand, the tests conducted showed that the use of intensity adjustment and CLAHE on images that showed levels of intensity sufficient for the processing, according to our first criteria, produced results less efficient than those obtained without the use of these enhancements.

It is also possible to generate lines with positioning different from the middle point of the two obtained lines, by adjusting the parameters of the initial and final points. This feature may be of interest when the level of the terrain makes it difficult for the robot to move along the center line. Fig. 11 shows the image with the original center line (in black), one line dislocated to the left by 20% (in red) and another line (in green), dislocated 20% to the right of the original center line.

Fig. 11 Generation of multiple navigation paths

IV. Conclusions and Future Work

An algorithm for path extraction in-between tree rows was developed for applications in agricultural terrestrial wheeled-mobile robots. Image processing and morphological operations were used to build a method capable of identifying lines and generating a center line to be followed. The algorithm is capable of identifying if an image needs enhancements on its levels of saturation by analyzing its representation into the HSV color map.

Computational analysis performed with several images showed that the proposed method is capable of obtaining a navigation path with a low processing time and high-level of precision in different environments. In future works, authors will explore the possibilities for the application of the developed method in prototypes of terrestrial mobile robots.

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