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Efficient Algorithm for Real-Time Specific Weed Leaf Classification System

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Abstract: A computer-assisted automatic spray control system for herbicides is an important issue from the economical perspective, but it is also a technical challenge. Weeds cause harm to crops by competing for water, light, nutrients and space, reducing crop yields and inhibiting the efficiency of machinery. To overcome the negative impact of weeds on crops, a real-time weed classification system is important. Although there a large volume of methods were developed for this system, previous studies have lacked accuracy and efficiency. In this paper, two real-time specific weed classification algorithms, Edge Link Detection and Watershed Segmentation, were compared and analyzed for weed leaf classification. The accuracy of classification using the Edge Link Detection algorithm (93%) was greater than that when using Erosion followed by Watershed Segmentation Algorithm (92.5 %). However, the elapsed time for image processing with Edge Link Detection was 321.7 m sec compared to 102.3 m sec with the Erosion followed by Watershed Segmentation Algorithm. In conclusion, the Erosion followed by Watershed algorithm was more efficient at weed leaf classification than the Edge Link Detection when images were captured by a CCD camera.

Key words: weed, edge detection, erosion, watersheding, machine vision.

1. Introduction

A weed is defined as ”any plant growing in a place at the wrong time and doing more harm than good”, which competes with a crop for water, light, nutrients and space and therefore reduces crop yields and affects the efficiency of machinery. Thus, those plants which interfere with human activity in crop and non-crop areas are considered weeds.

Mechanical cultivation is commonly used method for weed control, but the removal of specific weeds from a field is a primary limitation with this method. To solve this limitation, agricultural chemicals (herbicides and fertilizer products) are most widely used. In fact, the success of agriculture is attributable to the effective use of chemicals/herbicides.

A real-time weed leaf classification system or machine vision system is important for this purpose. The author of [1] developed and tested a machine-vision-system-guided precision sprayer, the accuracy of which was 75% in weed zone. Thus weed recognition component became a critical form operation and can significantly affect crop yield.

Agricultural production experienced a revolution over the past century with advances in the development of farm machinery and technology. However, there are still tasks that have remained largely untouched by the revolution. Before the 2000’s, the role of hand laborers did not change and they still performed wearisome field operations. Automatic farming needs a system to classify particular or distinct weeds and to determine the exact position of the weeds in an agricultural field,

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which is one of the most important tasks in real-time crop maintenance. So the technology for “smart” field machinery has been developed, which automatically localizes distinct weeds and performs precise treatment.

Improved efficiency in chemical application would also increase profitability in the agricultural production sector. Some spraying systems exist, such as Selectively Spraying, Spot Spraying or Intermittent Spraying, which are attached to the herbicide applicators. Thus, farmers need alternatives for weed control in order to reduce the usage of chemicals and cost of production, as well as prevent the time that is consumed during hand hoeing.

Herbicides are vitally important in weed control and high crop yield; however these chemicals often produce harmful effects [2]. Normally herbicides are applied uniformly because weeds are highly aggregated and tend to occur in clumps and/ or patches and also remain relatively stable in size and location from year to year [3]. Herbicides are applied to whole fields of weeds like a blanket, without taking into consideration the types of weeds in the field [4]. Furthermore, in comparison to the uniform application method, the reduction of herbicide not only provides an economic advantage, but it is also environmentally friendly. The author of [5] has reported that when real-time weed sensing such as remote sensing and machine vision is applied, then there is a possibility that the amount of herbicides in a control patch sprayer will be reduced. Both the systems essentially require image acquisition and image processing techniques. The authors of [6-7] have found that the size of the image varies by an order of megabytes for which the elapsed time is 0.34s to 7s. But the elapsed time depends on image resolution and the type of weed, for which the algorithm uses hardware configurations.

Many researchers have examined strategies to reduce production costs, protect the environment and control weeds with less herbicide. Several and algorithms by [8-9] have been developed for real-time selective herbicide systems that can classify, localize and recognize weed leaves. The author of [10] used PDA as a processing device and measured the Weed Coverage Rate to discriminate between narrow and broad leaves. A system that could use spatial distribution information in real-time and apply only the necessary amounts of herbicide to the weed-infested area would be much more efficient and minimize environmental damage. Therefore, a high spatial resolution, real-time weed molestation detection system seems to be the solution for site-specific weed management.

Although there, a large volume of methods were developed for a real-time automatic sprayer control system, previous studies have lacked accuracy and efficiency. The objective of this research is to develop a vision-based algorithm by comparing currently available algorithms, Erosion followed by Watershed and Edge Link Detection [11-12]. We created a real-time machine vision system algorithm that recognizes the absence of weed and differentiate the presence of broad weed leaf and narrow weed leaf. This algorithm could also be used to construct and evaluate a classifier capable of detecting and recognizing the type of weeds to be killed by the appropriate herbicides using the automatic sprayer control system. In this research, the automatic sprayer control system was used, which included a CCD camera, Central Processing Unit (CPU), decision box and two dc pumps for spraying (setup shown in Fig. 1. The images were taken at a distance of 4 m and at an angle of 45 with the horizontal, in a selected agricultural field.

The rest of the paper is organized as follows. First, we discuss the work related to this field. Then in the following two sections, we discuss the overview of our methods for the classification of the real-time specific weed leaves and results of the proposed algorithms and comparison with results from previous studies are discussed in results and discussion section. Finally, we will provide concluding remarks about the efficiency of our algorithm.

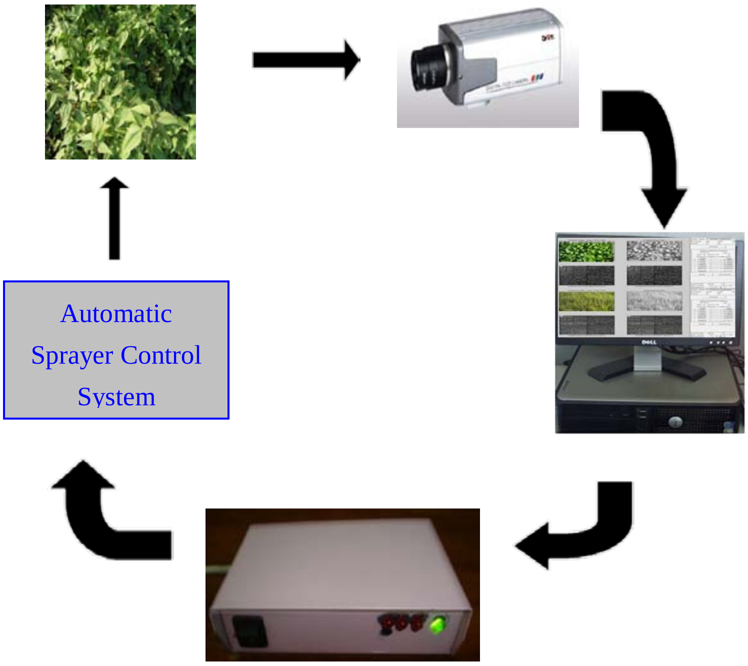

Fig. 1 Automatic Sprayer Control System

2. Material and Methods

In the proposed algorithm involving the Edge Link Detection method, the color (RGB) images were converted to gray scale images for easy and fast processing, and then the canny filter was applied to the gray scale images to reduce the amount of data.

In this algorithm, we applied the canny filter because it is computationally inexpensive in comparison to Sobel, Prewitt and Robert's operators. The canny filter first smoothes the image to eliminate the noise, and then find the image gradient to highlight regions with high spatial derivatives. The algorithm then tracks along these regions and suppresses any pixel that is not at the maximum (non-maximum suppression). The gradient array is now further reduced by hysteresis. Hysteresis is used to track along the remaining pixels that have not been suppressed. Hysteresis uses two thresholds and if the magnitude is below the first threshold, it is set to zero, means made a non-edge. If the magnitude is above the high threshold, it is made into an edge. And if the magnitude is between the 2 thresholds, then it is set to zero unless there is a path from this pixel to a pixel with a gradient above T2 [13].

However, the canny operator performs better than all these operators under almost all scenarios, so in this technique the canny filter was used for finding the best edges and then the proposed algorithm (Edge Link Detection) links the edges together with each other. For example ′A′ is an image and ′B′ is a structuring element (which in this case is a "canny filter"), which determines the edges of the image ′A′ using the structuring element ′B′, as shown in Fig. 2.

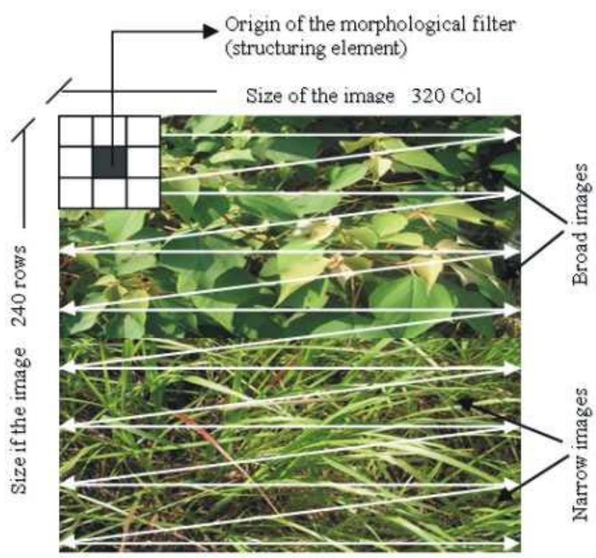

Fig. 2 Raster Scanning of Image using 3x3 Mask

The mathematical equation for edge detection is shown in eq. (1):

$$\begin{aligned} &A \otimes B = A - (A * B) \\ &= A \bigcap (A * B)^{c} \\ &\{B\} = \{B^1, B^2, B^3 ....B^n\} \\ &A \otimes \{B\} = ((...((A \otimes B^1) \otimes B^2)...) \otimes B^n) \end{aligned} \tag{1}$$

In the next step, a raster-scanning technique, as shown in Fig. 2, was used to detect and link edge points together into lists of coordinate pairs. Where an edge junction is encountered, the list is terminated and a separate list is generated for each of the branches. Two lookup Tables, LT1 and LT2, were created to store the edge junction and ending points, respectively. To test whether the center pixel within a 3X3 neighborhood is a junction/ending in LT1/LT2, the center pixel must be set and the number of transitions/crossings between 0 and 1, as one traverses the perimeter of the 3X3 region, must be 6 or 8 for junction and 2 for ending. Pixels in the 3X3 regions are numbered as follows:

$$\begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}$$

Another method that is used for image segmentation in the field of mathematical morphology is watershed transform. It is used to extract the boundaries of a given image with high pixel value. In geography, a watershed is the ridge that divides areas drained by different river systems. A catchment basin is the geographical area draining into a river or reservoir, i.e., the watershed transform finds ”catchment basins” and ”watershed ridge lines” in an image by treating it as a surface where light pixels are high and dark pixels are low. The watershed transform applies these ideas to gray-scale image processing in a way that can be used to solve a quality of image segmentation problems, which means that the concept of watershedding is just like dam construction. In this algorithm the color images were converted to gray scale images for easy and fast processing. An image segmentation step was conducted to divide the image into two classes: plant and background (soil). The gray scale image ‘A’ of the plant class was eroded by a structuring element ‘B’. The following equation shows the construction of the structuring element and the erosion of the image by that structuring element [14] and is given in eq. (2):

$$\begin{aligned} &B_z = \left\{ b + z \middle| b \in B \right\} \forall_z \in E \\ &A \Theta B = \left\{ z \middle| (B)_z \cap A^c \neq \varphi \right\} \end{aligned} \tag{2}$$

where ‘A’ and ‘B’ are the input image and the structuring element respectively. After eroding the image A by structuring element B, the Watershed Segmentation algorithm is applied with the general syntax that is indicated by eq. (3):

$$L = watershed\,(A) \tag{3}$$

This algorithm computes a label matrix identifying the watershed regions of the input image A. The elements of L are integer values greater than or equal to 0. The elements labeled 0 do not belong to a unique watershed region. These are called “watershed pixels”. The elements labeled 1 belong to the first watershed region, and the elements labeled 2 belong to the second watershed region and so on. By default, the watershed algorithm uses 8-connected neighborhoods for 2-D inputs. For larger dimensions, the Watershed algorithm uses the connectivity is given by eq. (4):

$$CONFNDEF\,(NDIMS\,(A), {}'MAXIMAL') \tag{4}$$

The following equation shows the sum of all pixels in the resultant image, which is further used for classification purpose. The addition of pixels is done by using eq. (5):

$$Sum = \sum_{i=1}^{M} \sum_{j=1}^{N} (i + j) \tag{5}$$

where M and N are the number of rows and column, respectively, and $'i'$ and $'j'$ indicate the intensity value of a pixel at x and y coordinates. The resultant value is then compared with the selected threshold (T) for classification of weeds into broad or narrow weeds. This threshold, T, is selected after performing various trials on the images stored in the database. The Fig. 3 presents the flow chart of the erosion followed by the watershedding segmentation algorithm.

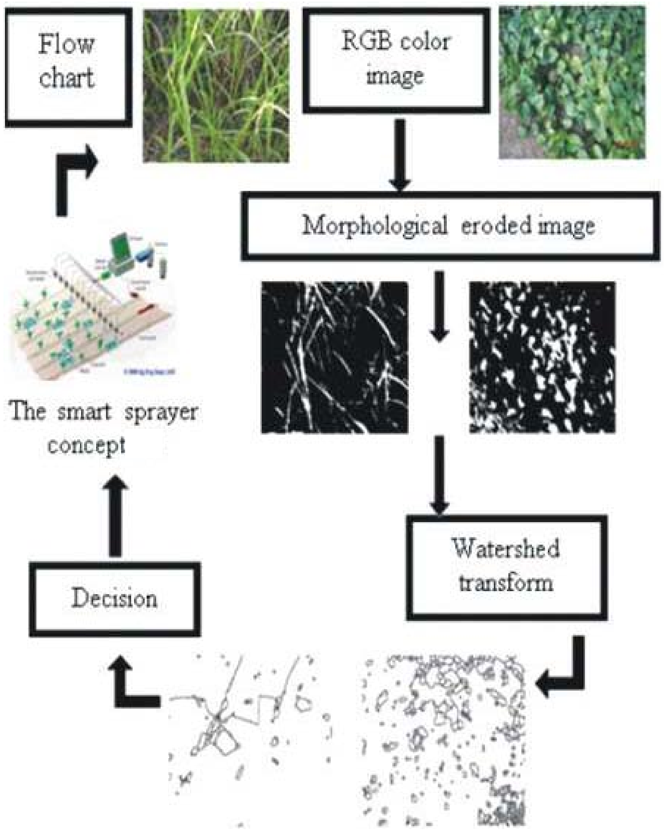

Fig. 3 Concept of Erosion followed by Watershed Segmentation Algorithm

3. Results and Discussion

This paper presents an efficient algorithm for real time specific weed leave classification system. Table 1, Fig. 4 and 5 show the accuracy of classification and efficiency of Edge Link Detection. The given algorithm processes two types of images for broad and narrow weeds. The algorithm produced reliable accuracy in detecting the presence or absence of weed cover. For areas where weeds were detected, the results showed up to 93% classification accuracy with over 350 sample images. The percentage of each class is given in Table 1 for which the percentage of each category has been determined by applying the proposed algorithm to the database of 350 images, with 150 samples from broad category of weeds, 150 samples from narrow category of weeds and 50 samples of no or little weeds, from which we determined the percentage for each category by adding the pixels of all the processed database of images of br--oad, narrow and no or little images.

The elapsed time for running this algorithm was 321.7 m sec. The developed algorithm is feasible for an automatic sprayer control system that consists of a CCD camera, CPU, decision box and the DC pump, whose setup is shown in Fig. 1. For the developed algorithm, first the CCD camera captures the image and then forwards it to CPU and then the CPU recognizes the image by using the proposed algorithm. The DC pump applies the right type of herbicides using this algorithm.

Table 1 Classification of different weeds using edge link Detection algorithm.

Different Types of Weeds	Elapsed Time (m sec)	Classification Accuracy (%)
Broad	350	93
Narrow	320	92
Little or no Weed	295	100

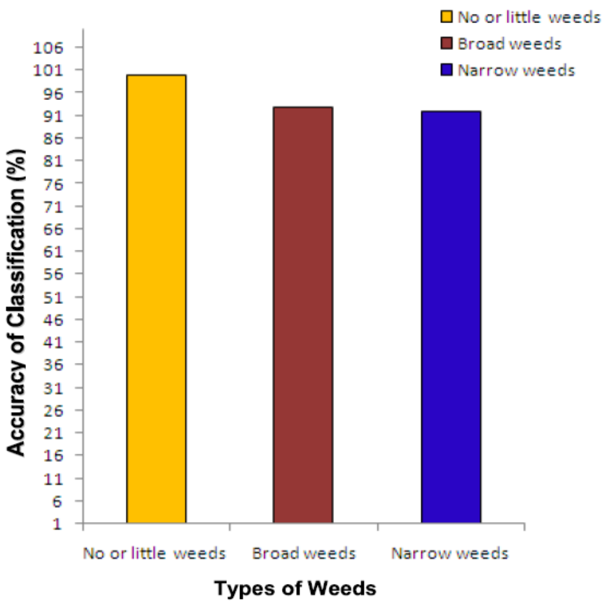

Fig. 4 Accuracy of Classification of Different Types of Weeds using Edge Link Detection Algorithm

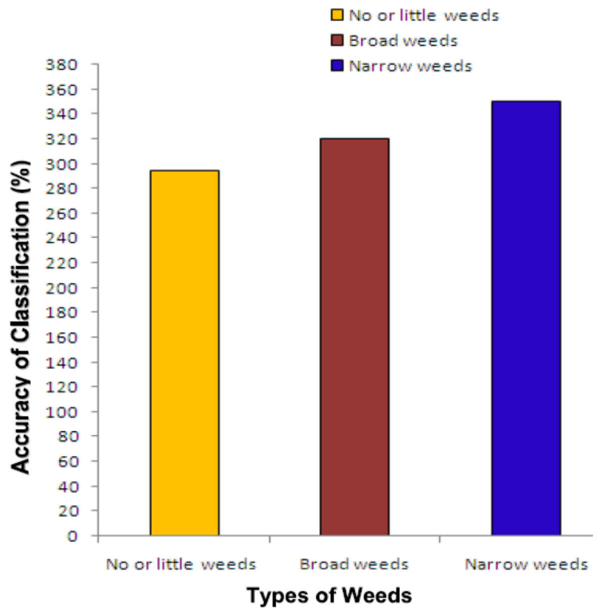

Fig. 5 Efficiency of Edge Link Detection Algorithm on Different Types of Weeds

It is to be noted from Table 2 and Fig. 6 and 7 that the accuracy of classification and efficiency using the erosion followed by Watershed Segmentation algorithm. For this algorithm, there are two categories of weeds: broad and narrow. First, Erosion was applied to remove the unwanted details for fast and easy processing and then the morphological Watershed transform was applied. The algorithm had reliable accuracy in detecting the presence or absence of weed cover. For areas where weeds were detected, the results showed up to 92.5% classification accuracy for over 350 sample images, for which the proposed algorithm took 102.3 m sec to process. The percentage of each class is given in Table 2.

Table 2 Classification of different weeds using erosion followed by watershed segmentation algorithm.

Different Types of Weeds	Elapsed Time (m sec)	Classification Accuracy (%)
Broad	104	92
Narrow	108	90
Little or no Weed	95	100

Fig. 8 and 9 show the results of Edge Link Detection and Erosion followed by the Watershed Segmentation algorithm, respectively. These previously developed algorithms [11-12] were compared using manual threshold values. Fig. 10 and 11 show the results of different constant threshold values using these algorithms.

It is clear from the Fig. 10 and 11 that the best results were obtained using a constant threshold value (25000) for both algorithms (erosion followed by Watershed Segmentation and Edge Link Detection).

The accuracy of classification through the Edge Link Detection algorithm was superior, with the highest accuracy at 93% (Table 3, Fig. 12 and 13). However, classification using the Erosion followed by Watershed segmentation algorithm was more efficient as it took a lot less time (102.3 m sec) than the Edge Link Detection algorithm (321.7 m sec). Because Edge Link Detection can only classify images with sharp edges, it may not be useful in the classification of specific weeds in terms of elapsed time.

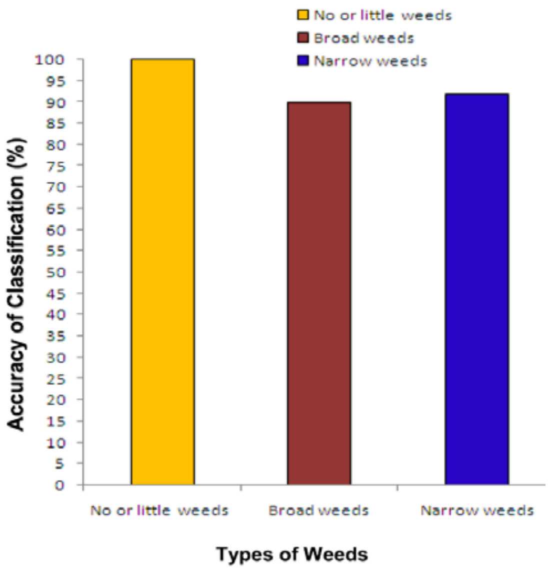

Fig. 6 Accuracy of Classification of Different Types of Weeds using Erosion followed by Watershed Segmentation Algorithm

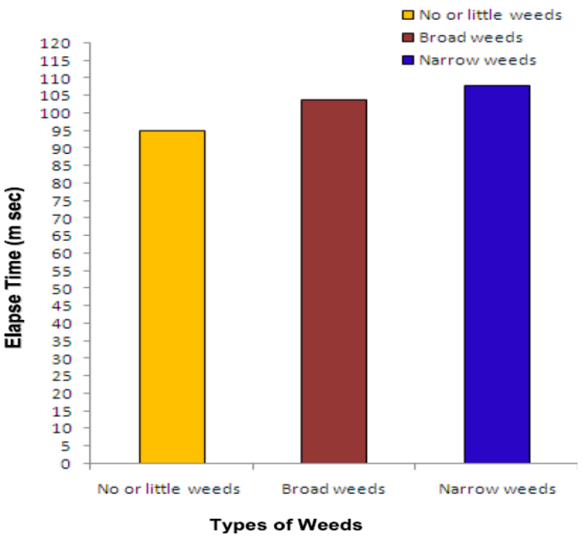

Fig. 7 Efficiency of Erosion followed by Watershed Segmentation Algorithm on Different Types of Weeds

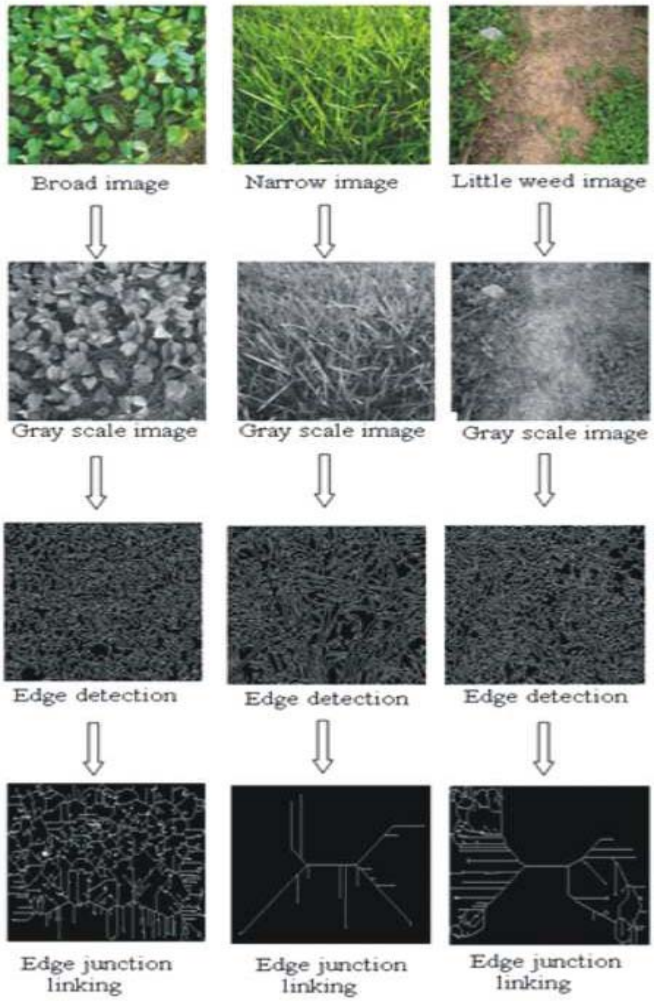

Fig. 8 Classification Results of Different Types of Weeds using Edge Link Detection Algorithm

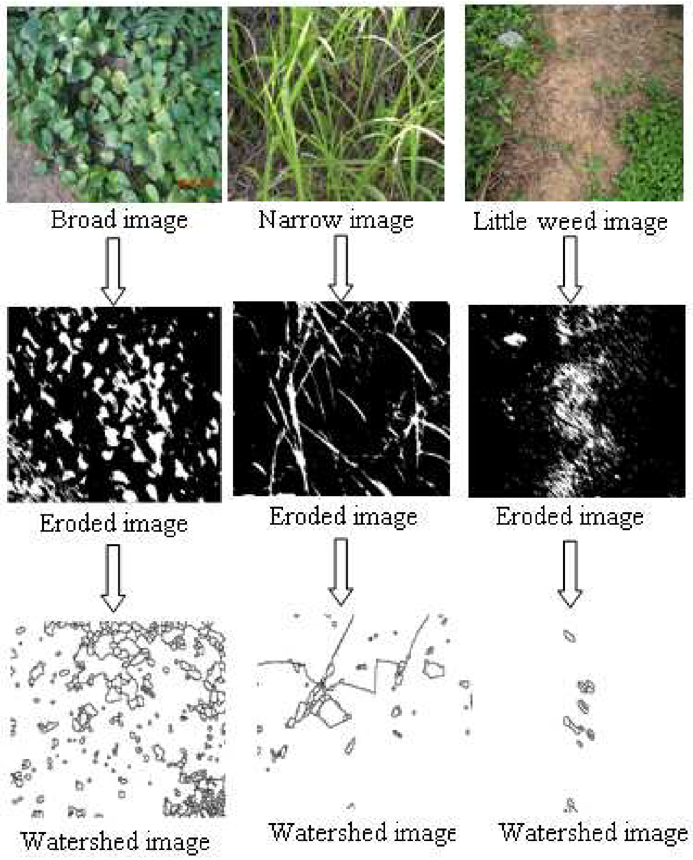

Fig. 9 Results of Erosion followed by Watershed Segmentation Algorithm on Different Types of Images Taken by CCD Camera

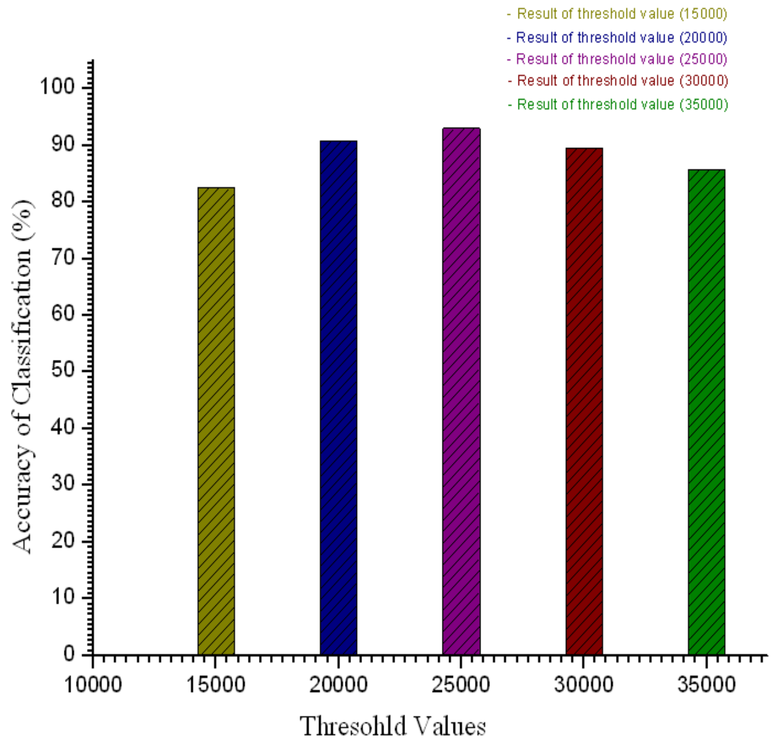

Fig. 10 Classification based on Erosion followed by Watershed Segmentation Algorithm using Different Manual (Constant) Threshold values

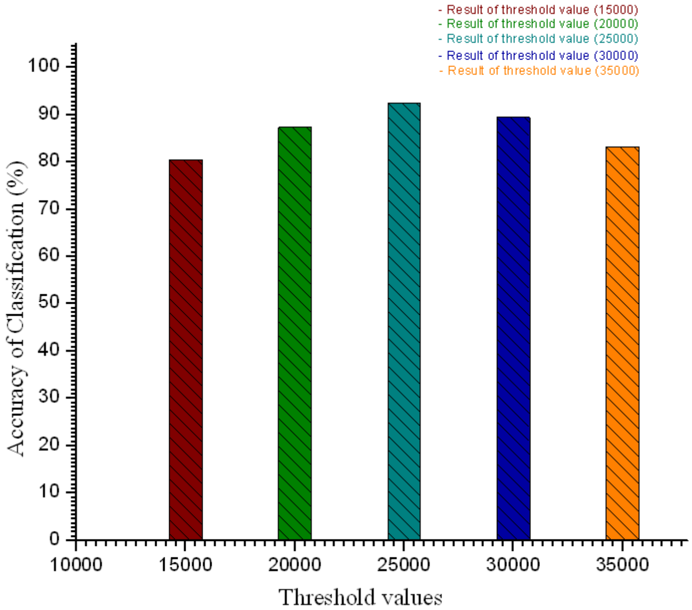

Fig. 11 Classification based on Edge Link Detection using Different Manual (Constant) Threshold values

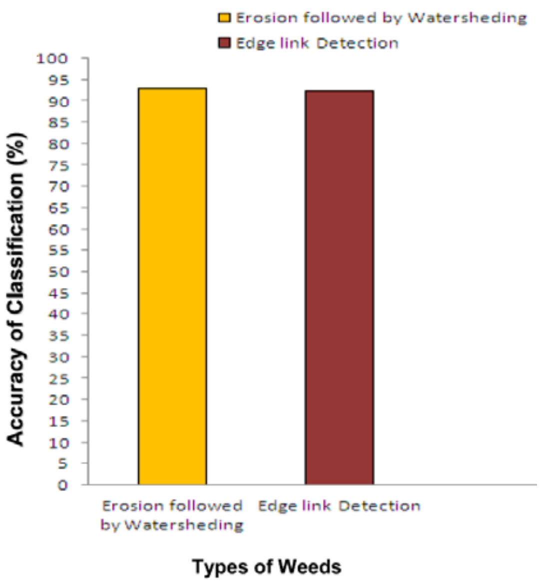

Fig. 12 Comparison of the Developed Algorithm in-term of Accuracy

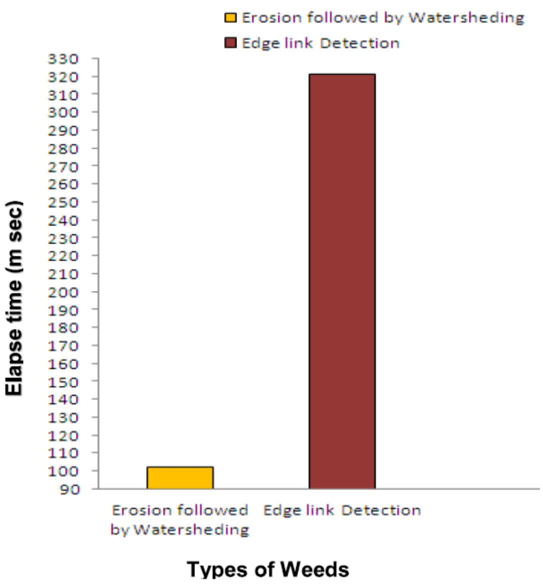

Fig. 13 Comparison of the Developed Algorithm in-term of Efficiency

Table 3 Comparison of algorithms

Developed algorithms	Elapsed Time (m sec)	Classification Accuracy (%)
Erosion followed by Watershed Segmentation	102.3	93
Edge Link Detection	321.7	92.5

Comparison with Existing Algorithm:

The developed algorithm was compared with some of the existing algorithms [15-21] in terms of accuracy and efficiency. In terms of efficiency, the current algorithm was the most efficient of all tested. It was also more accurate than some of the algorithms that were tested. Fig. 14 and 15 show the results of the comparison between the developed algorithm and the existing algorithms.

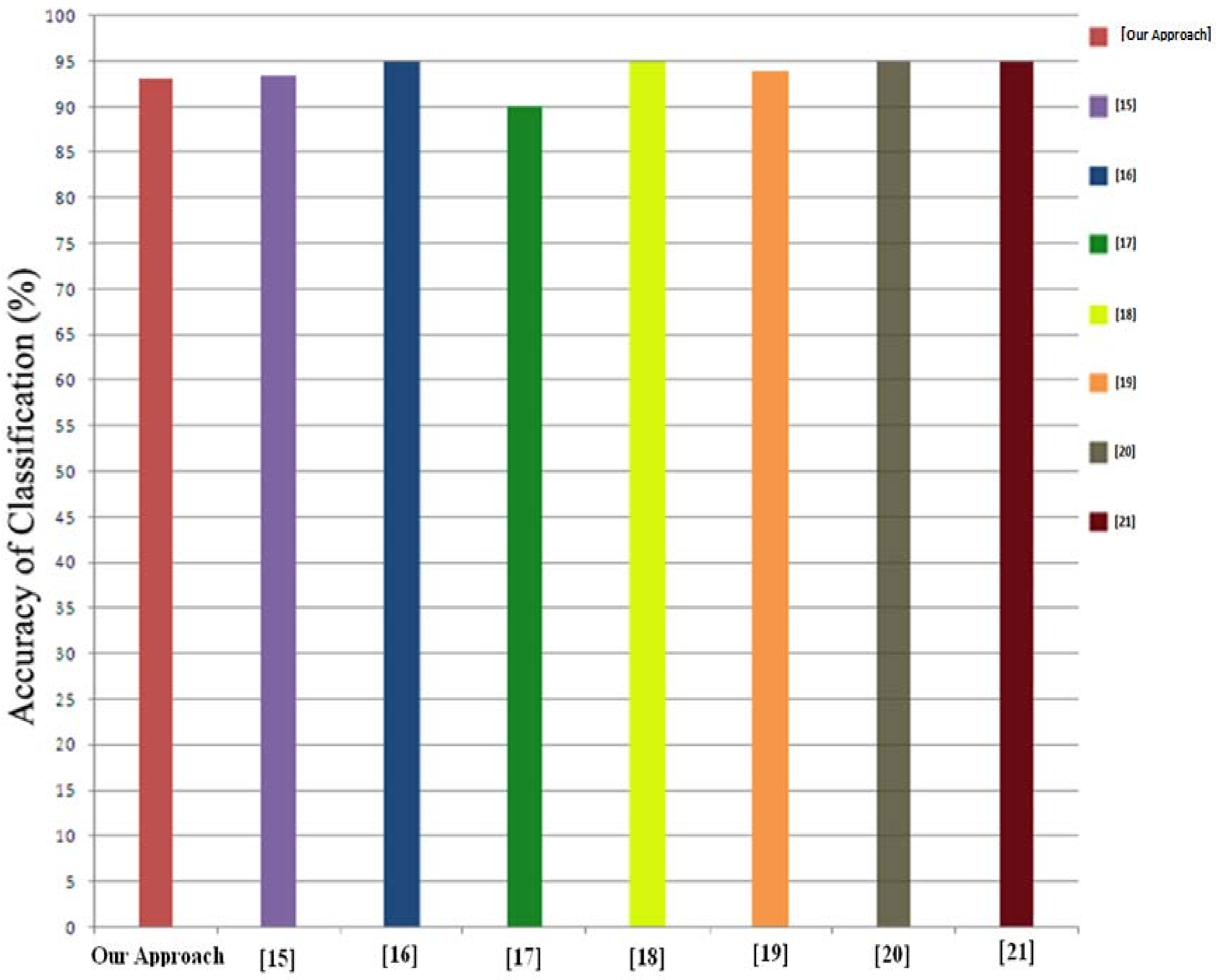

Fig. 14 Comparison of the Developed Algorithm with Existing Algorithms in-term of Accuracy (%)

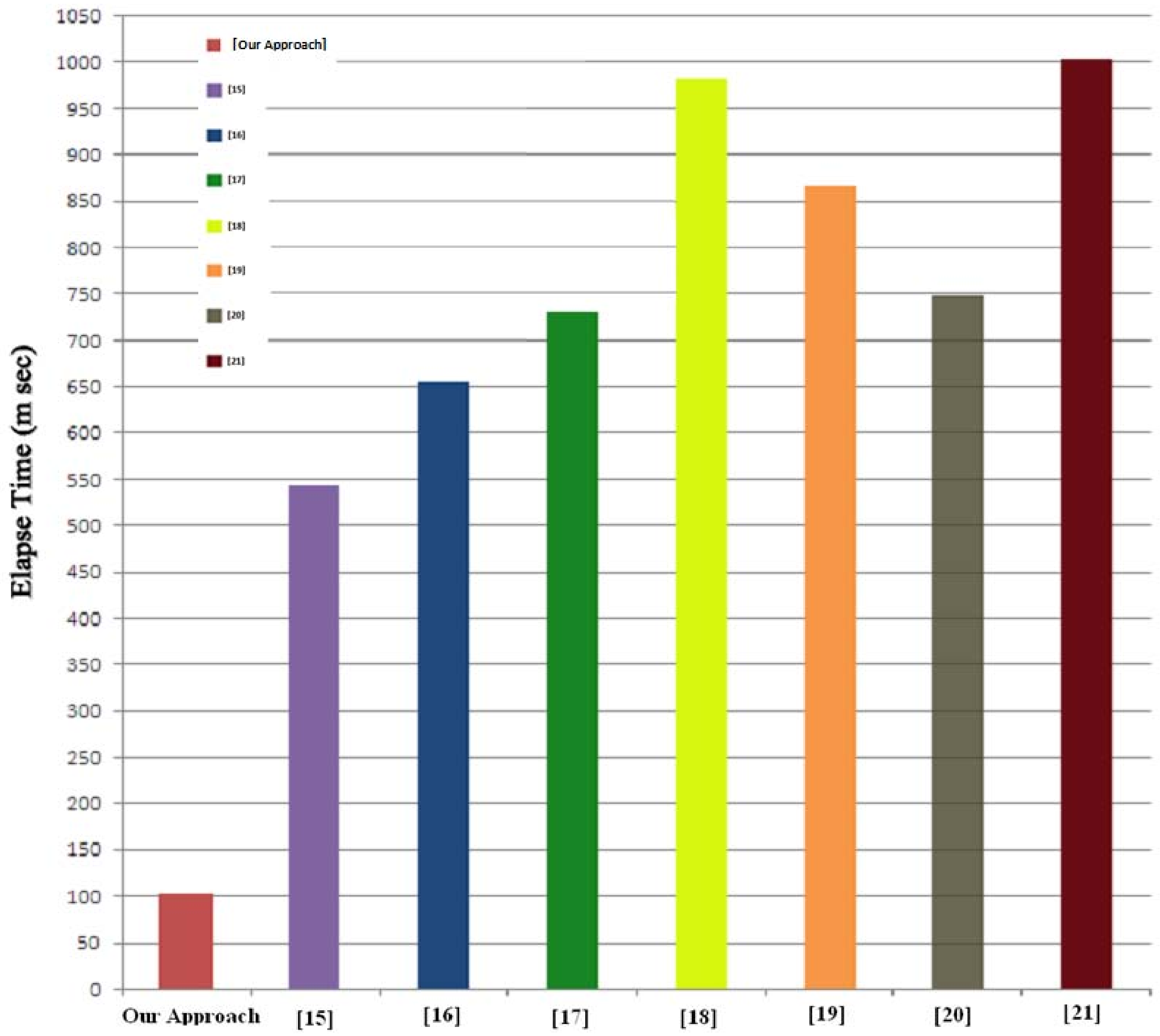

Fig. 15 Comparison of the Developed Algorithm with Existing Algorithms in-term of Efficiency (m sec)

It is demonstrated from Fig. 14 and 15 that the Erosion followed by Watershed Segmentation algorithm is most efficient and more accurate than existing algorithms. In the field of mathematical morphology, the Watershed transform is the method of choice for image segmentation because it allows segmentation of an image with a high accuracy in the absence of a threshold operation. As a result, the application of the Watershed to the gradient of the initial image gives too many areas [22]. To reduce the effect over the segmentation, a pseudo-skeleton operation was applied.

This finding is significant when determining the most suitable algorithm for use in a real-time, specific weed discrimination system, whose setup is shown in Fig. 1.

4. Conclusions

In this research, we proposed two algorithms for real-time specific weed detection and classification and then compared these with existing algorithms. These weed detection/classification algorithms were developed and tested in the lab using a database of 350 images for selective spraying of weeds with a vision recognition system. This study has described a more effective preprocessing and processing technique for dealing with weed classification in order to improve the precision and efficiency of weeding strategies.

The accuracy of classification with the Edge Link Detection algorithm (93%) was greater than that with the Watershed Segmentation algorithm (92.5%). However, of the Edge Link Detection took longer to process the database of images (321.7 m sec) than the Watershed Segmentation algorithm (102.3 m sec). Therefore, the Erosion followed by Watershed algorithm is most efficient with images captured by a CCD camera.

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