Evaluation of the accuracy of the recognition algorithm of an autonomous robotic device to control weeds

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Abstract. The main problem in the agro-industrial sector is the use of harmful herbicides, resulting in some of the weeds becoming more resistant to common herbicides and therefore using more and more powerful and expensive options. To overcome this problem, it is necessary to reduce the amount of herbicide use. The proposed study aims to develop a system that can detect and map weeds and perform mechanically applied spot spraying. The weed detection techniques described in this study include several aspects: imaging, a new algorithm for detecting plants through contour and colour segmentation. The method developed can detect weeds at early stages of growth. Further development of the methods is aimed at solving problems related to complex background without soil treatment, faster image acquisition speed and shorter processing time for spot injection in real time. The results of the experiment show that the proposed hybrid method can be used as a tool for weed control.

1. Introduction
Weeds adversely affect the yield of beet crops by taking away their nutrients. At present, chemical weeding with herbicides is widely used as a traditional method of weed vegetation control. However, herbicides are not considered as an effective method of weed control because of their negative environmental impact. Moreover, consumers are increasingly choosing natural, organic foods that have not been exposed to toxic chemicals. There are also non-chemical weeding methods, ranging from electrical to mechanical or physical control methods.

Many companies introduced a robot sprayer for weed control. Such selective spraying methods are still depend on the use of herbicides but can reduce their use [1].

The purpose of this study was to create and test in the laboratory a new prototype for the recognition of weeds and to examine its feasibility for successful application in agriculture. For this purpose, we have developed a universal platform for mechanical weeding of weed vegetation with point application of herbicides.

2. Materials and methods
To carry out the study, a system with one camera was used, which was previously installed at a certain angle, to calculate the coordinates of objects (figure 1). The limitation of this installation is that the robot is suitable for use on a flat surface, as due to irregularities, the focal length and angle of the camera will greatly. The stand itself consists of a platform with guides and a carriage installed on it which is driven by a worm gear by a step motor which provides movement along all three planes. On
the Z-axis there is a camera Logitech HD Webcam C930e, resolution 1920x1080, speed of capture 120 psi. Images are imported into the weed recognition module through the bus and processed in System Visual Studio. The camera was calibrated in such a way that pixel coordinates of the weeds could be converted into real ones. The camera was fixed and the carriage changed its position to obtain 10 calibration photos which were used to get the camera's own parameters and distortion coefficients. Besides, after the calibration of the system, the parameters of the starting point set for the coordinate conversion. High image processing speed and system simplicity are also important aspects of this robotic weeding system in real time [2].

![Laboratory test bench for weed vegetation control.](image)

Figure 1. Laboratory test bench for weed vegetation control.

3. Image processing and weed recognition

The processing of images was carried out in two stages. The first step was to detect the culture (beet) and weeds which was aimed at obtaining 4 images, where the crop and weeds were defined as red and green (1) and the background was gray (soil) (2). Then, based on the difference in colors, an algorithm was used which compared the hue, saturation and value (HSV) of each pixel with a predetermined color (figure 2) [3].

At the beginning we get a picture of the whole landscape (figure 2 (a)). We set tolerances (± 0.1) for all values that in future work can be used for differentiation of plants and background in all other obtained images. This is followed by colour segmentation to identify green plants. Figure 2 (b) shows the result of the extraction method, in which large green leaves (considered beets) are clearly visible, while other plants (weeds) are less distinct and are separated from grey shades of soil and black tray. Since there was a lot of visual noise in the soil (stones, lumps of soil, etc.), the image was filtered and a black mask was applied. In addition, due to the influence of light, it was possible to see darkened plants which would affect the calculation of plant centroids. Therefore, the image was filled with contour completion to fill the voids. The next step was to segregate the culture so that weeds could be identified. Three segmentation methods were proposed, tested and compared. The first two segmentation algorithms suggested obvious differences in area and color between weeds and beet. The first of these algorithms was based directly on the difference in area. The area was calculated using Python function and compared with the contour of the already developed base to define it as belonging to a culture (beet).
Figure 2. Image processing protocol: (a) original image; (b) use of colour segmentation to determine green plants in the background; (c) obtaining a binary image; (d) identification of a cultivated plant.

The problem of weed and culture intersection is solved by methods of comparison of the size of foxes and crop contours and unwanted plants [4]. Therefore, the second method based on erosion and dilatation operations was implemented. Using this method, images were eroded until all weeds were detected, as shown in figure 2 (d). Then smoothing took place as shown in figure 2 (c) with increasing erosion coefficient. Thereafter, an operation was performed to superimpose the obtained contours on the original image to determine the culture, as shown in figure 2 (a). The following is the result of segmentation - highlighting in red and building weed centroids. The processing time of the two algorithms for figure 2 was 0.0968 s (in area) and 0.0346 s (based on erosion and dilatation), respectively, on our equipment as described above [5]. Table 2 below shows the results of image processing the number of errors where the system made an incorrect determination of weed culture. The analysis was performed on 50 photographs by visual processing and comparison. Plants were divided into two groups - weeds and useful cultures [6, 7].

However, due to changes in light intensity in the environment, fixed thresholds were not sustainable enough. To correct this deficiency, a color reproduction algorithm was adopted [8, 9].
| No. photo | A number of the recognizable beet | In total beets | A number of the recognizable weeds | In total weeds | Quantity of errors of. % | Number of errors during beet removal | Number of weed spreading errors |
|-----------|----------------------------------|----------------|-----------------------------------|---------------|-------------------------|----------------------------------|-------------------------------|
| 1         | 3                                | 4              | 13                                | 10            | 14.29                   | 25.00                            | 30.00                         |
| 2         | 2                                | 3              | 14                                | 12            | 6.67                    | 33.33                            | 16.67                         |
| 3         | 2                                | 3              | 11                                | 9             | 8.33                    | 33.33                            | 22.22                         |
| 4         | 4                                | 4              | 11                                | 12            | 6.25                    | 0.00                             | 8.33                          |
| 5         | 2                                | 3              | 10                                | 12            | 6.67                    | 33.33                            | 16.67                         |
| 6         | 5                                | 5              | 13                                | 14            | 5.26                    | 0.00                             | 7.14                          |
| 7         | 3                                | 3              | 11                                | 11            | 0.00                    | 0.00                             | 0.00                          |
| 8         | 2                                | 3              | 13                                | 13            | 6.25                    | 33.33                            | 0.00                          |
| 9         | 2                                | 3              | 14                                | 12            | 6.67                    | 33.33                            | 16.67                         |
| 10        | 3                                | 3              | 11                                | 11            | 0.00                    | 0.00                             | 0.00                          |
| 11        | 3                                | 3              | 12                                | 10            | 15.38                   | 0.00                             | 20.00                         |
| 12        | 4                                | 3              | 11                                | 13            | 6.25                    | 33.33                            | 15.38                         |
| 13        | 3                                | 2              | 13                                | 13            | 6.67                    | 50.00                            | 0.00                          |
| 14        | 2                                | 2              | 14                                | 12            | 14.29                   | 0.00                             | 16.67                         |
| 15        | 2                                | 2              | 11                                | 11            | 0.00                    | 0.00                             | 0.00                          |
| 16        | 4                                | 3              | 12                                | 12            | 6.67                    | 33.33                            | 0.00                          |
| 17        | 3                                | 3              | 12                                | 11            | 7.14                    | 0.00                             | 9.09                          |
| 18        | 4                                | 4              | 13                                | 12            | 6.25                    | 0.00                             | 8.33                          |
| 19        | 4                                | 3              | 14                                | 14            | 5.88                    | 33.33                            | 0.00                          |
| 20        | 3                                | 3              | 12                                | 12            | 0.00                    | 0.00                             | 0.00                          |
| 21        | 2                                | 2              | 14                                | 14            | 0.00                    | 0.00                             | 0.00                          |
| 22        | 3                                | 2              | 13                                | 12            | 0.00                    | 50.00                            | 8.33                          |
| 23        | 2                                | 3              | 12                                | 13            | 0.00                    | 33.33                            | 7.69                          |
| 24        | 1                                | 1              | 11                                | 12            | 7.69                    | 0.00                             | 8.33                          |
| 25        | 3                                | 2              | 14                                | 15            | 0.00                    | 50.00                            | 6.67                          |
| 26        | 2                                | 2              | 14                                | 12            | 14.29                   | 0.00                             | 16.67                         |
| 27        | 4                                | 3              | 12                                | 14            | 5.88                    | 33.33                            | 14.29                         |
| 28        | 2                                | 2              | 13                                | 13            | 0.00                    | 0.00                             | 0.00                          |
| 29        | 1                                | 1              | 14                                | 14            | 0.00                    | 0.00                             | 0.00                          |
| 30        | 1                                | 1              | 14                                | 12            | 15.38                   | 0.00                             | 16.67                         |
| 31        | 3                                | 3              | 10                                | 11            | 7.14                    | 0.00                             | 9.09                          |
| 32        | 3                                | 3              | 12                                | 13            | 6.25                    | 0.00                             | 7.69                          |
| 33        | 4                                | 4              | 11                                | 13            | 11.76                   | 0.00                             | 15.38                         |
| 34        | 4                                | 4              | 10                                | 11            | 6.67                    | 0.00                             | 9.09                          |
| 35        | 1                                | 2              | 12                                | 10            | 8.33                    | 50.00                            | 20.00                         |
| 36        | 1                                | 3              | 13                                | 10            | 7.69                    | 66.67                            | 30.00                         |
| 37        | 2                                | 2              | 10                                | 10            | 0.00                    | 0.00                             | 0.00                          |
| 38        | 2                                | 3              | 10                                | 9             | 0.00                    | 33.33                            | 11.11                         |
| 39        | 2                                | 2              | 12                                | 11            | 7.69                    | 0.00                             | 9.09                          |
Using the results obtained, it is possible to compare the obtained result with the actual one. The final result of segmentation can be seen in figure 2 (a) in which the beet centroids were marked. The processing time was 1 s. The methods of combining shape and colour were simple and fast [2, 10].

4. Conclusions
In this study, a machine vision-based algorithm was implemented and tested to recognize weed vegetation by combining contour and color detection of the beet crop with further marking of centroids, followed by removal. Tests have shown that the accuracy of the recognition algorithm autonomous robotic device to control weeds using the proposed method is up to 83.5. The analysis of the dependence of the recognized crop in the image on the real amount of weeds was also carried out. Various areas of treated soil were taken to assess the operability of the algorithm. Other parameters such as soil to lens height, the same recording mode, permanent lighting and others were also constant, only the cultivated areas were changed.

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