A Measurement System for On-line Estimation of Weed Coverage

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***Abstract*—This paper describes two different solutions for the estimation of weed coverage. Both measuring systems discriminate the weed from the ground by means of the color difference between the weed and ground and can be used to on-line control tractor sprayers in order to reduce weedkiller use. The solutions differ with respect to the sensor type: one solution is based on a digital camera and a computer that analyzes the images and determines the weed amount, while the other simpler solution makes use of two photo detectors and an analog processing system. The camera-based solution provides an uncertainty of a few percentage, while the photo detector-based one, though extremely cheap, has an uncertainty of about 5% and suffers from changes in light conditions, which can alter the estimations.**

***Index Terms*—Image color analysis, image processing, photodetectors.**

I. Introduction

THE ESTIMATION of the actual weed coverage in crop fields is an important task for the reduction of weedkiller usage and consequently of environment pollution. The herbicide dose is usually evaluated by sight by making a rough estimation of the overall field weed coverage; this simple and heuristic method can lead to a waste in weedkiller and however does not take the non uniformity of the weed throughout the field into account. For these reasons an automated measuring system that is able to estimate local weed presence and control the weedkiller sprayers could greatly reduce herbicide abuse [1].

This paper describes two different solutions, which are based on the optical analysis of light reflected by the weed and the ground and can be used for lined crop fields.

The first solution takes advantage of a digital video camera connected to a computer. The digitized images are processed by a software, which is designed to analyze the spectrum of the reflected light in order to separate the ground from the areas covered by weed.

The second solution is based on a complete analog system that relies on two photo-diode detectors and a flash lighting system, which is required in order to reduce the influence of sunlight changes on the coverage estimation. This solution is remarkably faster and cheaper than the video camera-based one, even though a larger uncertainty is expected due to both the light changes and the different colors of the expected weed.

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II. Optical Weed Estimation

Weed detection by means of optical techniques has been investigated by several authors who have employed different approaches. Some authors have tried to identify the different species of plants by analyzing the contour [2] or other characteristics [3]–[5]. Although these techniques can give good results, they require a remarkable computation power in order to carry out the identification algorithms.

Other authors have investigated techniques based on plant reflectance which shows changes in the near infrared range [6]. These changes can be used to distinguish plants from other materials, but cannot be used to divide plants into different kinds [7], [8]. Nevertheless a simple plant detection is useful in lined crop fields where the weed estimation can be carried out between the crop lines [9].

This paper investigates the performance of measuring systems that rely only on the visible part of the light spectrum in order to permit the use of low-cost commercially available video cameras. This choice reduces the cost of the camera-based system, but also reduces the estimation capability of the analog-based system [9], as is described in Section V. The proposed measuring systems are designed for use in lined crop fields and thus no attempt to discriminate between weed and plants has been made.

III. Coverage Reference Values

The first problem in performance evaluation is the determination of the correct or "true" weed coverage. A "standard" instrument for coverage determination does not exist. The authors therefore validated the algorithms by applying them to images that were also manually analyzed. The characterization was therefore carried out on a set of 21 images, which corresponded to different light conditions and coverage in the range of 1–35%; coverage values above this limit were not considered since this situation is not likely to be encountered in practical cases. Each image was manually edited separating the weed from the ground (Fig. 1). The coverage was eventually determined with a simple counting procedure. The editing of each image was performed several times by different operators; the mean value was assumed as the reference value while the standard deviation was used as an indicator of the intrinsic uncertainty of the standard values. A standard uncertainty of below 0.5% of coverage was obtained in all images.

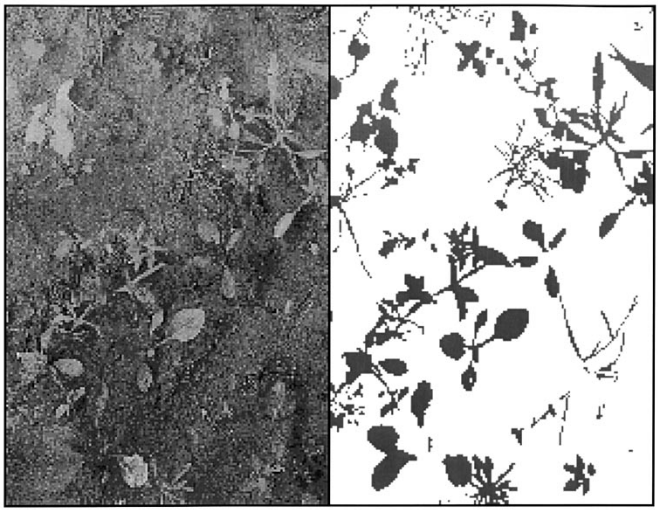

Fig. 1. An example of an image that is used for the algorithm calibration. On the left is the original image, and on the right is the edited result.

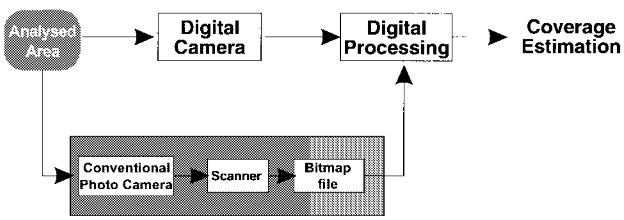

Fig. 2. Block diagram of the digital camera-based estimator.

IV. Camera-Based Solution

A. Principle

The basic scheme of the camera-based solution is shown in Fig. 2: A digital camera is used to capture a color image of the analyzed area. Such a digitized image is then analyzed by means of a software that is designed to count the number of weed pixels and compute the coverage estimation.

The figure also shows an alternative solution, which was used to obtain the reference digitized images. Such a solution employs a conventional photo camera, which was used to produce photographs of fields with different weed coverage and under different light conditions. The images were eventually scanned and made available to both the program, which estimates the coverage, and to different operators, who manually estimate the actual weed coverage, as explained in Section III.

The digitized images that were used during the software development were composed of about three hundred thousand points or "pixels," a value which is typical of several economic video cameras.

Each pixel is represented in the computer by means of a three bytes, which give the amount of red, green, and blue colors (RGB triplet) of the pixel, therefore each image requires a computer memory which is less than one megabyte.

Weed is characterized as having a "green" color while the ground is characterized as being of a brown or grey color. A discrimination can therefore tempted on the basis of suitable thresholds on the three color levels. The RGB triplet represents the actual color luminance and thus a normalization is required in order to select the pixels with respect to the relative color only. The authors used the root-mean-square value of the RGB colors as a luminance indicator to which each pixel triplet is normalized

$$lum_v = \sqrt{R_v^2 + G_v^2 + B_v^2} \tag{1}$$

where R_v, G_v, B_v are the RGB values of the vth pixel.

The normalization process adds a constraint between the three R, G, B values so that only two independent variables remain. The weed discrimination can therefore be tempted by fixing two thresholds: one on the maximum red fraction C_R and one on the minimum green fractions C_G

$$C_R = \frac{R_v}{lum_v} \qquad C_G = \frac{G_v}{lum_v}. \tag{2}$$

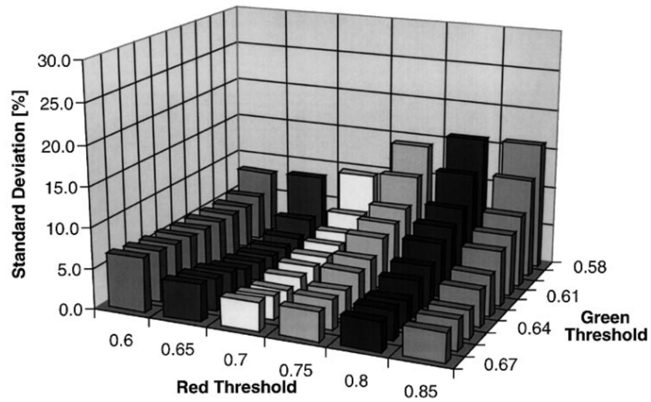

Fig. 3. Standard deviation of the difference between the estimated and actual coverage as a function of red and green thresholds.

B. Threshold Selection and Experimental Results

The threshold selection can be carried out by minimizing the coverage difference between the estimations and the standard values of all the reference samples. Fig. 3 shows the standard deviation of such differences for different values of the red and green thresholds. The standard deviation has a minimum of about 2% for $C_{G_{\min}} = 0.61$ and $C_{R_{\max}} = 0.66$.

An analysis of the areas that are classified as weed on the different images shows that, in many cases, pixels are classified as ground even though they belong to visibly solid weed and other isolated pixels are wrongly classified as weed. Both phenomena can be reduced at the expense of a limited computational complexity increase by means of a "cleaning" algorithm, which is applied after the first classification. The cleaning process consists of removing the spots that are classified as weed but are completely surrounded by ground pixels and of promoting the spots classified as ground, but completely surrounded by weed-classified pixels, to "weed." An example of the cleaning effect is shown in Fig. 4, where a detail of an image is reported along with the rough and cleaned result. Fig. 5 shows the standard deviation of the difference between estimated and actual values after the cleaning process has been applied.

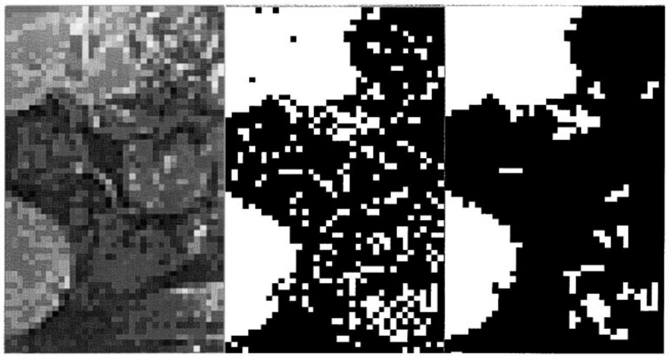

Fig. 4. Effect of the "cleaning" algorithm. On the left is the original image, in the middle is the recognized weed without cleaning, and on the right is the cleaned image.

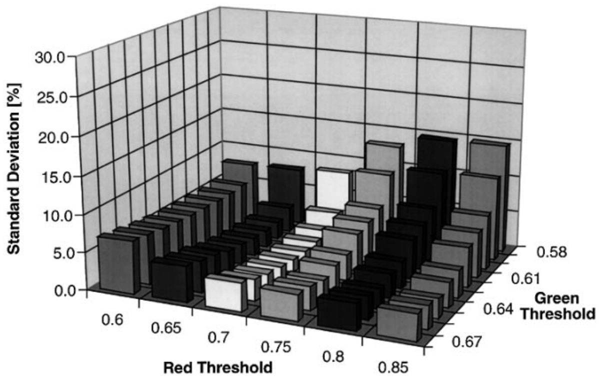

Fig. 5. Standard deviation of the difference between estimated and actual coverage, as a function of red and green thresholds after the cleaning process is applied.

The optimal spot dimension in pixels depends on the actual spatial resolution of the images. With the resolution of the images used in this experiment, a value of three pixels gave the best results. The minimum standard deviation is reduced down to about 1%, while the optimal color thresholds change slightly when the cleaning algorithm is used and become $C_{G_{\min}} = 0.65$ and $C_{R_{\max}} = 0.7$.

The figure shows that the threshold selection is not critical since the estimation standard deviation remains reasonably low for threshold changes of up to about 5%.

Fig. 6 shows the results of the 21 images that compose the set: the vertical tick lines represent the reference values and are equal in height to the reference standard deviation; the vertical thin lines represent the values estimated by the camera-based solution with their standard deviation. All the estimations lie within the reference values, plus or minus twice the standard deviation, thus confirming the good overall behavior of the algorithm.

The total processing time, including the cleaning process, is less than 2 s on a standard Pentium-based PC. This value is low enough to permit the use of the system for on-line controlling the farm tractor weedkiller sprayers.

In addition, one should note that such a total processing time includes the visualization of the acquired images and is obtained using a program written in C++. Remarkably better results can be expected by removing the user interface over-

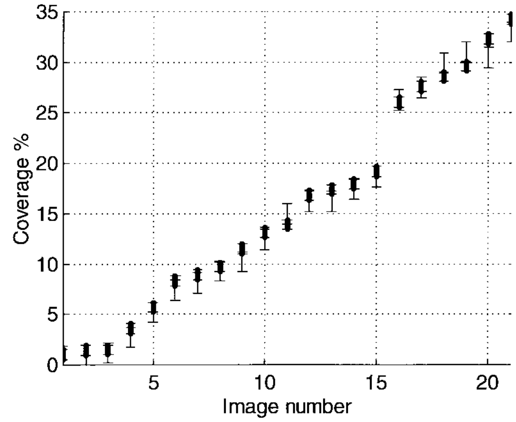

Fig. 6. Estimation of the camera-based method and actual coverage. The vertical bars represent the estimated standard deviation.

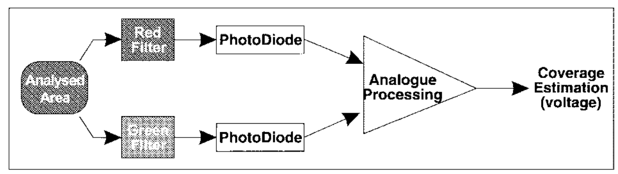

Fig. 7. Block diagram of the analog estimation system.

head and by optimizing the computation intensive procedures that deal with the pixel processing.

V. Analog Solution

The camera-based solution gives rather interesting results, but requires the use of a computer and has a response time that, although limited, cannot be reduced below some hundreds of milliseconds.

A complete analog system could be both faster and cheaper so that several units could be installed on a single tractor to allow the weedkiller dispersion to be performed on each single weed spot.

The basic scheme of a completely analog system is shown in Fig. 7 and is composed of two wide band photo-detector coupled to a green and a red optical filter. The voltages produced by the photo-detectors are eventually combined together by mean of a simple operational amplifier-based circuit to obtain a voltage that represent the coverage estimation.

The main problem of the analog technique, which operates on the mean green and red light values in a specific area, is the variability of the chromatic composition of light, ground and weed.

In fact, the use of a single detector for an area that comprises weed and ground does not allow one to discriminate between a reduced area of bright weed and a larger area of weed with a pale color. This problem is increased by light color changes that introduce another variability source.

The performance of the analog system can be foreseen by processing the mean red and green value of the 21 images already employed for the characterization of the camera-based solution.

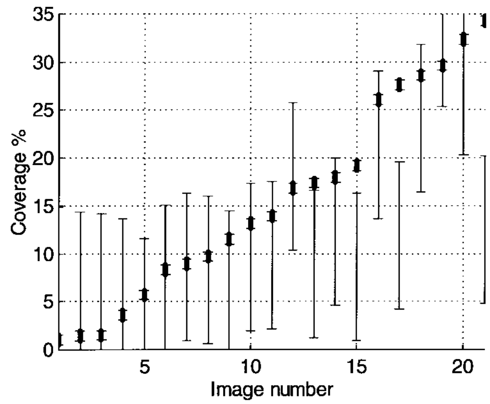

Fig. 8. Coverage estimations based only on the mean values of the red and green colors. The vertical bars represent the estimated standard deviation.

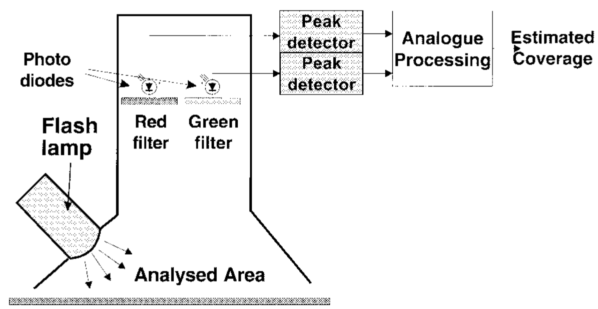

Fig. 9. Modified analog measuring head.

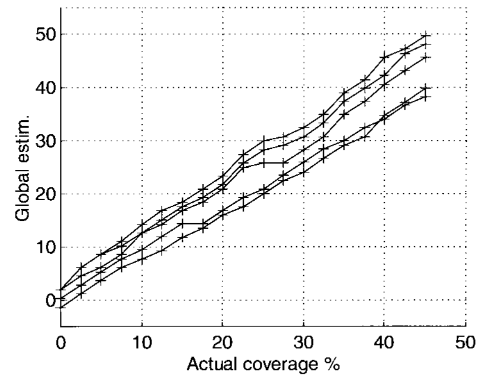

Fig. 10. Response of the analog system with different types of weed.

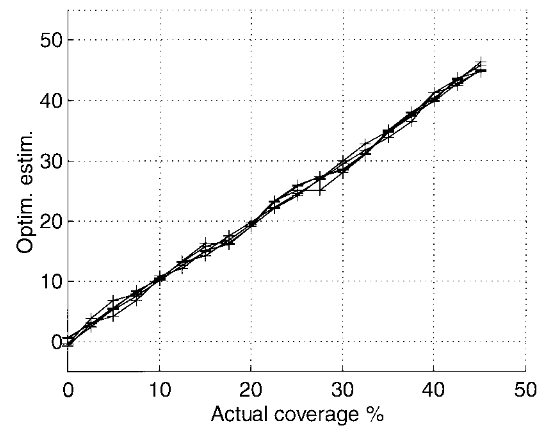

Fig. 11. Coverage estimations for different weed species if the coefficients are determined by taking that weed type into account.

A predefined equation that correlates the mean red and green values does not exist, the authors therefore tried different relations and eventually chose a formula that takes the sum and difference of colors into account

$$c = k_1 + k_2 \frac{\overline{R} - \overline{G}}{\overline{R} + \overline{G}} \tag{3}$$

where $\overline{R}$ and $\overline{G}$ are the mean red and green color values and k_1 and k_2 are two coefficients to be determined with a minimization process.

Fig. 8 shows the estimations and reference values and can be compared to Fig. 6. The standard deviation of the difference between the estimations and the reference values is of about 10% and thus an analog system which is simply based on two sensors seems to be unable to provide a sufficient accuracy.

Better results, with a standard deviation reduced to about 4%, can be obtained if the analysis is restricted to "homogeneous" images characterized by similar light conditions.

Subsequent investigations have therefore been performed with an acquisition system, which is equipped with a xenon "flash" lamp, in order to reduce the effect of the color changes due to environmental light. The modified measuring head is shown in Fig. 9. The flash lamp is fired with a frequency of about 10 Hz. The sensor outputs are sent to two analog peak-detectors that operate as sample and hold circuits and maintain the sensor outputs that are generated during the flash lamps. The peak detector outputs are eventually sent to the analog processing circuit that implements a simple linear formula

$$c = k_1 + k_2 v_r + k_3 v_g \tag{4}$$

where k_1, k_2, and k_3 are three coefficients to be determined during the calibration phase.

The output voltage is eventually sampled used as coverage estimation value.

Tests have been performed with five different weed species, which have different colors and reflectances (Echinochloa, Ficus, Solanum nigra, Panicum dichotomiflorum, Sorghum halepense).

Each test consisted in recording the sensor outputs for coverage values in an extended range of 0–50%. The actual coverage was estimated by cutting the weed edges to allow an easy geometrical estimation to be performed. All the tests were performed in subdued light to minimize the effect of the light changes. After the acquisition of all the values a least square estimation was carried out to determine the three coefficients of (4).

Fig. 10 shows the estimations versus actual coverage for the four different weed species. A standard deviation of about 4% coverage is obtained and this agrees with the values expected from the analysis of the images with a similar illumination.

The estimation for the different weed species shows the effect of their different colors thus suggesting that a coefficient determination performed on a single weed type would give better results on that weed. Fig. 11 shows the coverage estimations of the five weed types performed by optimizing the coefficients for that weed type. As expected the estimations are rather better than in the previous case and the standard deviation is reduced to about 1%.

This value is comparable with the results obtained by the camera-based solution, however this low uncertainty cannot be maintained in the field due to the number of influence quantities that can be encountered during real operations. As an example, other tests were performed by changing the soil composition and humidity conditions. The standard deviation increased in this case to about 4%, even though the coefficient estimations were carried out on a single weed type.

The analog system is therefore intrinsically less accurate than the camera-based solution and can only be used if standard deviations of about 5% are acceptable.

VI. Conclusions

Two solutions for weed coverage estimation have been presented that can be used for on-line control of weedkiller procedures. The camera-based solution provides uncertainty of the order of 1%, at the expense of medium complexity and cost, while the analog solution is quite cheap, but exhibits an uncertainty of about 5% of coverage. Both solutions are suitable for on line operations: the analog solution has a response time of less than 200 ms, while the camera-based system has a response time of less than 2 s.

The camera-based solution can operate regardless of the light conditions and allows a post validation of the estimations to be performed on the stored images. A new ruggedized prototype is now being tested in the field to evaluate the actual performance in adverse environmental conditions.

The analog solution presents problems in sunny conditions where the flash light system might not be able to provide a controlled light. Further investigations are needed to evaluate the performance that can be obtained by integrating an infrared detector in the analog measuring head.

Acknowledgment

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