TÜBİTAK

**Turkish Journal of Agriculture and Forestry**

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2019) 43: 164-173
© TÜBİTAK
doi:10.3906/tar-1803-8

# Design, development, and evaluation of a target oriented weed control system using machine vision

**Ömer Barış ÖZLÜOYMAK[1],*, Ali BOLAT[2], Ali BAYAT[1], Emin GÜZEL[1]**
[1]Department of Agricultural Machinery and Technologies Engineering, Faculty of Agriculture, Çukurova University, Adana, Turkey
[2]Eastern Mediterranean Agricultural Research Institute, Republic of Turkey Ministry of Food Agriculture
and Livestock, Adana, Turkey

**Received:** 02.03.2018 • **Accepted/Published Online:** 09.12.2018 • **Final Version:** 01.04.2019

**Abstract:** The objective of the study was to develop and test an automatic machine vision-based spraying robot for the detection, tracking, and spraying of artificial weeds by using LabVIEW programming language. The greenness method was used to distinguish green objects in the image. A time-controlled spray nozzle was run according to the presence of an artificial weed and its coordinates. A mobile test bench was built and the spraying system with a webcam was operated at speeds of 0.42, 0.54, 0.66, 0.78, and 0.90 km $h^{-1}$, so as to be able to see the performance of the system. The amount of deposits on the ground in the spray pattern was evaluated on the test area and used in comparisons for site specific and broadcast spraying methods. A spraying solution containing brilliant sulpho-flavin (BSF) tracer (0.4 g $L^{-1}$) and filter papers were used to compare the deposition of spray pattern achieved on the ground with both methods. According to the results, site-specific spraying application saved on average 89.48%, 79.98%, and 73.93% application volumes for 500 ms, 1000 ms, and 1500 ms spraying durations, respectively, at all spraying speeds is compared to broadcast spraying application. As one would expect, deposits on the filter papers decreased with increasing spraying speed. In addition, operating the system with 1000 ms nozzle controlled site specific spraying at different speeds did not cause a significant difference in the amount of deposits in the spray pattern and spraying accuracy as compared to the broadcast spraying method.

**Key words:** Image processing, LabVIEW, machine vision, patch spraying, weed detection

## 1. Introduction

Weed control is an important issue in the production of agricultural products. Weeds compete with crop plants for sunlight, water, space, and nutrients. The use of these resources by weeds rather than by crop plants reduces crop yields and quality, and increases production costs. The use of herbicides is the most preferred method for weed control because manual weeding is a laborious operation. Herbicides should be applied uniformly to provide better weed control.

In recent decades there is a clear tendency to reduce the use of herbicides in agriculture (Blasco et al., 2002; Tian, 2002; Tellaeche et al., 2008; Sabancı and Aydın, 2017). Many researches are working towards finding the best solutions for accurate and minimal herbicide usage to reduce water contamination and the harmful effects of herbicides on the environment (Yang et al., 2003; Jafari et al., 2006a; Loni et al., 2014). Herbicide consumption is reduced significantly by using patch spraying to control weeds site-specifically without losing efficacy (Yang et al., 2002; Yang et al., 2003; Timmermann et al., 2003; Jafari et al., 2006a; Loghavi and Mackvandi, 2008; Tellaeche et al., 2008; Shirzadifar et al., 2013; Loni et al., 2014; Gonzalez-de-Soto et al., 2016). Many new technologies have been developed to protect the environment and obtain safer agricultural products. Machine vision and optical sensor technologies are commonly used in research for detection and localization of weeds in the field.

Nowadays, image processing is used for measuring leaf dimensions, detecting weeds, color analyses and classification, etc. The applications of image processing have been commonly found in fields such as medicine, industry, geology, security, and agriculture (Sabancı and Aydın, 2017). Digital image processing deals directly with an image, which is composed of pixels. The pixels are comprised of spatial coordinates that indicate the position of the points in the image and intensity (gray level) values. The RGB color model used in color representation is based on the human perception (Zhou et al., 2010).

Today, the researchers compare two methods called site-specific and broadcast spraying. The site-specific spraying

---

* Correspondence: ozluoymak@cu.edu.tr

This work is licensed under a Creative Commons Attribution 4.0 International License.

method aims to spray specific targets while reducing the use of pesticides (Berenstein and Edan, 2018). On the other hand, broadcast applications deliver spray over the entire surface area of the field or crop foliage. Tellaeche et al. (2008) outlined an automatic machine vision system for detection and differential spraying of weeds in corn crops. They designed a new strategy that involves segmentation and decision making and found that this strategy achieved an important outcome in cost savings and pollution reduction. Tian (2002) developed and tested an automatic sprayer system controlled by a real time computer vision technology. The potential chemical savings with that system were between 52% and 71% in normal field conditions. Yang et al. (2003) developed a simple and effective image processing system for using herbicides in site specific applications. They integrated image processing and fuzzy logic algorithms for weed coverage determination and site-specific herbicide application. In that study, they used MATLAB matrix programming language for reducing processing time and computational effort. Shirzadifar et al. (2013) developed a machine consists of vision based, real-time, site-specific herbicide application system and evaluated it under field and laboratory conditions. In their study, they used both MATLAB and LabVIEW (National Instruments Corporation, Austin, Texas, USA) software programs for comparing the magnitudes of spraying delay. In the eradication of weeds, while both applications (patch spraying and conventional spraying) had the same effect, they used 75% less herbicide compared to the conventional method in the patch spraying application. Jafari et al. (2006b) investigated various color feature extraction algorithms for separating the plants from the soil as well as weeds from the sugar beets in their study. They could correctly detect 5 of the 7 types of weeds. Yang et al. (2002) developed an image processing model for maize fields to distinguish the crop from the weeds with a commercial digital camera. They reported that this model could be an important part of weed detection and mapping system in using site-specific application of herbicides. Sabancı and Aydın (2017) detected weeds and sprayed with a liquid by using a smart spraying machine. They chose the plant on the image by separating it into RGB channels and obtained a green color value by using image processing techniques. Wan Ishak and Abdul Rahman (2010) developed an automated sprayer with a camera to detect the presence of weeds and spray chemicals precisely in real time. They used this machine vision system with autonomous all-terrain vehicles (ATV) in the outdoor environment. The variation of daylight affects the light intensity for outdoor studies because it changes the RGB values of the agricultural products. That is why the images were captured according to the presence of clouds and the time of day. Loghavi and Mackvandi (2008) developed a prototype patch sprayer for target oriented weed control system. They integrated DGPS, GIS, and a microprocessor to the system in order to control solenoid-activated spray nozzles. Targeted weed patch herbicide application resulted in 69.5% savings compared to conventional application. Tangwongkit et al. (2006) developed a tractor mounted site-specific, real-time machine vision guided variable rate herbicide applicator between sugarcane rows. They stated that the flow rate accuracy was approximately 91.7% and herbicide consumption could be decreased by up to 20.6%. The light intensity was also a big problem for them; therefore a white plastic cover structure was used in order to avoid the negative effects of light intensity. Timmermann et al. (2003) realized site-specific weed control on 5 fields with a GPS guided sprayer to evaluate its ecological and economical effects. They reported that an average of 54% of herbicides could be saved.

Some studies mentioned above proved considerable herbicide savings of total application volume by using site-specific spraying. The solenoid valves mounted on the nozzles of these systems were opened or closed based on the intensity or percentage of the green color pixel values of weeds (Tian, 2002; Yang et al., 2002; Timmermann et al., 2003; Tangwongkit et al., 2006; Loghavi and Mackvandi, 2008; Shirzadifar et al., 2013; Sabancı and Aydın, 2014; Sabancı and Aydın, 2017). Although the existing systems worked as on/off switching of solenoid activated spray nozzles and assessed the herbicide disposal on total application volume, the amount of deposits on the plants has not been considered in these studies. The originality of this research is that besides the volumetric consumption and spraying liquid savings, the amount of deposits on artificial weeds, which were not found in prior research, were also examined and determined by using a spectrofluorophotometer.

The objective of this study was to develop a real-time interrow site-specific spraying system, based on machine vision technology by using LabVIEW programming language, and to evaluate the developed mobile prototype system under laboratory conditions.

## 2. Materials and methods

### 2.1. Materials

Research was carried out in the chemical application laboratory at the Department of Agricultural Machinery and Technologies Engineering of Çukurova University, Adana, Turkey. The automation and image processing units consisted of a webcam (Logitech C270) that captured the image of artificial weed frames, a data acquisition device (National Instruments, NI USB-6009), and a 12 V, 16-channel relay card. This relay card could draw a current of 20 mA from the microcontroller during a trigger signal. The mobile spraying test unit could move on rails with the help of a 0.37 kW, 3-phase, 4-pole electric motor (WAT, QS71M4B) coupled to a gear reducer (Yılmaz Redüktör, A12–71MNB). In order to adjust the speed of the spraying unit, a variable frequency controller (ABB micro drives, ACS355) was used on the system. The site-specific herbicide application system was developed for a single row and designed for interrow weed management. Acquired artificial weed images were sent to a laptop computer (Acer, Aspire, 4830TG) through a USB port to be processed. Automation and image processing were carried out by LabVIEW programming language. The camera was equipped with a complementary metal oxide semiconductor (CMOS) sensor and the maximum resolution of an image was 1280 × 720 pixels at full frame. The focal length of the optical system was 4 mm. Additionally, a pneumatically controlled spraying unit that consisted of a lubricator (STNC, TC 2010–02), air compressor (Sarmak, Çita), premix tank, 12 V DC normally closed solenoid valve (Tork, S101003145N), spray nozzle (Lechler standard flat fan nozzle, 110–02) with 110° spraying angle and 0.2 gal $\mathrm{min}^{-1}$ flowrate at 275.79 kPa (40 PSI) nominal pressure, and other necessary hardware were designed and built for the system (Figure 1). Thanks to the optical sensors (Pepperl+Fuchs, GLV18–8–450/115/120) placed on both ends of the spraying robot, the system moved back and forth automatically. The optical sensors detecting the border apparatus generated an output signal. This signal level was restricted to a maximum of 5 V by using the divider circuit card to protect the data acquisition device. An inductive proximity sensor (Sick, IME08–04NPSZW2S) that provides a counter output proportional to the motor shaft speed was used to measure the speed of the mobile robot by using the period value. A DC power supply (Pacific, 2305D+) was used to energize all sensors on the mobile system. A tachometer (Prova, RM-1500) was used to verify whether the measurement of the inductive proximity sensor was correct. Also, the spraying area for conventional spraying of the mobile robot was determined by using a pattern check apparatus (Teejet mobile patternator).

BSF (Brillant Sulpho Flavin) was used as tracer material and filter papers (Schleicher & Schuell, Whatman, Ø 42.5 mm) were used to determine the amount of deposit in the spraying pattern of the nozzle used. A spectrofluorophotometer (Shimadzu, RF-6000) was used to measure the deposit on filter papers. A shaking device (Nüve, SL 350) was used in order to remove tracer material from the filter papers placed in jars.

## 2.2. Methods

### 2.2.1. Object tracking and image processing method

Digital imaging method was used to separate the object (artificial weed, 74.92 mm × 98.90 mm) from its background. The mobile system was able to determine the existence of an artificial weed sample and track its coordinates by using LabVIEW interface. The RGB image captured by the webcam was segmented into red (R), green (G), and blue (B) components in order to obtain their pixel values separately. For separating artificial weeds from the background, the segmentation method was chosen because green pixels (artificial weed) have greater G components than R and B. The red (R) and blue (B) color values are subtracted from the green (G) color and multiplied by 2 to highlight the green color information (greenness method). It means that:

$$EG = 2G - R - B\,, \qquad (1)$$

where $EG$ means "excessive green" and $R$, $G$, and $B$ are the color components of the image. Many researchers used the

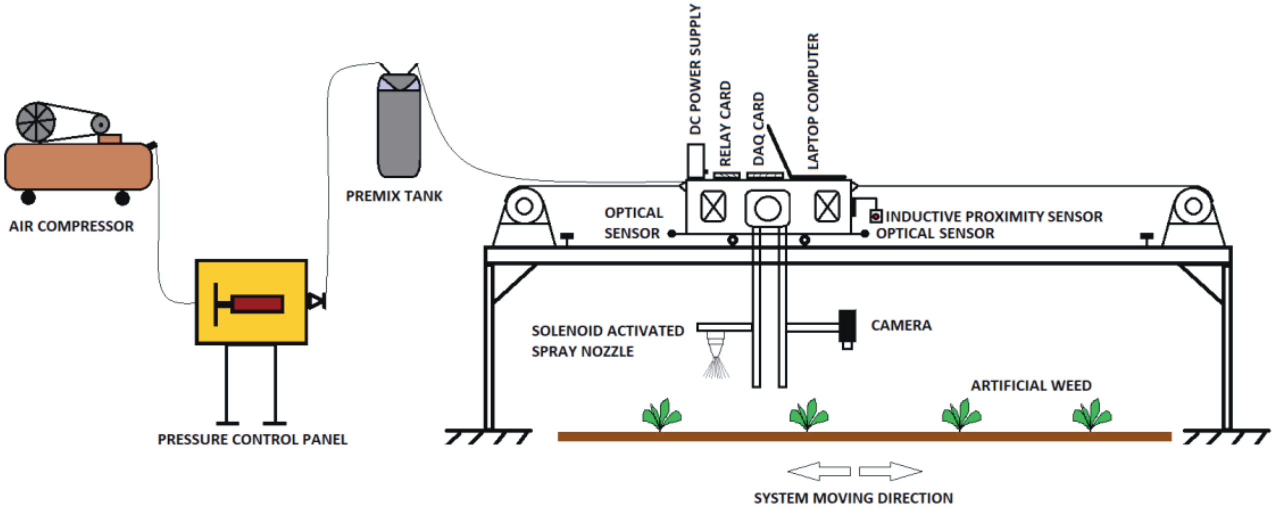


**Figure 1.** Real-time spray control system.

same method in their studies (Yang et al., 2002; Yang et al., 2003; Jafari et al., 2006b; Shirzadifar et al., 2013; Loni et al., 2014; Sabancı and Aydın, 2014; Sabancı and Aydın, 2017). The purpose of this method is to detect the greenness of the color. The block diagram of the image processing unit for spraying procedure is given in Figure 2.

The main advantage of using the greenness method is to eliminate light intensity better than the other methods. Also, Yang et al. (2003) and Jafari et al. (2006b) stated that different lighting intensity is a big problem for outdoor circumstances because clouds, shadows, and unsettled sunlight during the day might affect the optimum threshold value of the image. Some researchers that used image processing techniques other than the greenness method, had to use a white plastic cover structure, a light diffuser (cast acrylic cover), etc. over their vision sensors in order to avoid direct sunlight and reduce the effects of natural illumination (Perez et al., 2000; Tangwongkit et al., 2006; Loni et al., 2014).

In this study, "image thresholding method" was used for segmenting the image into 2 regions named background and object. By selecting a threshold value *T*, the objects could be extracted from the background. The object pixels were set to white (object point) and all other pixels were set to black (background point) in the image according to the threshold value. The segmented image is given by

$$g(x,y)=\begin{cases}1 & if\ f(x,y)>T\\ 0 & if\ f(x,y)\leq T\end{cases} \tag{2}$$

where *g(x,y)* is the processed image, *f(x,y)* is the pixel value of the image on the x-th column and y-th row, and *T* is the selected thresholding value (Gonzalez and Woods, 2008). The obtained image is named as a binary image.

Pixels were automatically assigned to weed or no weed by the selected threshold value during real-time operation. As a result of preliminary studies, the optimum threshold value of the image processing system was set at 40, where the intensity values range from 0 to 255. The same threshold value was also used by Yang et al. (2002) and Yang et al. (2003) in their studies. Different threshold values were tested by the researchers on a trial and error basis with many images, and this threshold value did not affect the image processing results for the images taken on the cloudy days when there was almost no shadow in the images.

Object tracking is the process of locating a moving object (or multiple objects) over time by using a camera. The mobile system tracked the artificial weed when its pixel values were larger than the preset threshold value by using a webcam. Coordinate information (x, y) of the artificial weeds was also transmitted to the computer instantaneously, while it was moving on the rail. Since the working direction of the mobile system is single plane, that is, there is no change in the y coordinates of the artificial weeds; the spraying process is only performed according to the x coordinate information of the weeds (only one way, only forward). The spraying process was carried out by activating the solenoid-activated spray nozzle, while the artificial weed was passing under the predefined coordinates in the system.

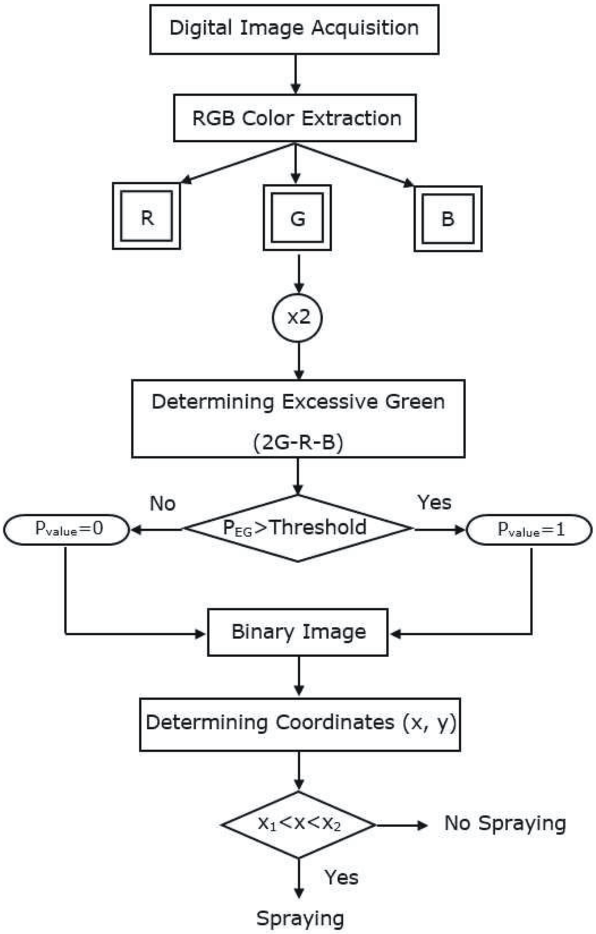


**Figure 2.** Image processing steps for spraying unit using greenness method.

### 2.2.2. System performance capability

A mobile test bench was designed to determine the performance of the tracking and spraying capabilities of the system (Figure 3). These parameters were tested and evaluated for 5 speeds (i.e., 0.42, 0.54, 0.66, 0.78, and 0.90 km $h^{-1}$) by using the LabVIEW software program. Artificial weed samples were placed one by one manually on the ground. A total of 5 pieces of artificial weed samples with 75 cm spacing were used for each trial. Spraying durations of the nozzle were set as 500 ms, 1000 ms, and 1500 ms by the user to ensure test stability, and it could be changed optionally if necessary.

System performance capability was calculated according to the mobile robot speed for each test as shown in Equation 3. Each test was carried out 3 times to confirm the reliability of the system.

$$\text{System Performance Capability (\%)} = \frac{A}{B} \times 100 \tag{3}$$

where $A$ is the number of artificial weed samples sprayed by the sprayer nozzle and $B$ is the total number of artificial weed samples.

### 2.2.3. Spray volume consumption tests

The automatic weed control system was realized in order to evaluate the economic impact of the system. Firstly, the spraying liquid was applied to the artificial weeds with 5 speeds, which were 0.42, 0.54, 0.66, 0.78, and 0.90 km $h^{-1}$. The nozzle was turned on or off from a data control unit via a solenoid valve. The nozzle was operated at 50 cm spraying height and the spraying pressure was 200 kPa for site-specific and broadcast spraying experiments. The nozzle spraying durations were adjusted to 500 ms, 1000 ms, and 1500 ms for site-specific experiments, respectively. Then, the spray outputs were collected on special glass containers to determine the sprayed liquid amount for each speed. Secondly, the same procedures were realized for broadcast spraying. Each test was replicated 3 times. At the end of testing, 2 methods (site-specific and broadcast) were compared in the use of spraying volume as volumetric consumption in the eradication of artificial weeds. Also, a spray pattern checking process was carried out for determining the spraying area of the mobile system.

### 2.2.4. Deposition measurements

To determine the deposits on the nozzle spray pattern, 3 filter papers with 20 cm spacing just behind each artificial weed were attached to the target points by means of clips in order to increase the accuracy of measurement, as shown in Figure 4.

The experiments were conducted with 3 replications for 5 speeds, and at the end of each cycle, the filter papers were removed with the aid of forceps and placed in separate glass jars. Thus, a total of 900 (5 artificial weeds × 3 filter papers × 3 replications × 5 speeds × 4 spraying processes (broadcast spraying, 500 ms, 1000 ms, and 1500 ms site-specific spraying)) filter papers were collected during the experiments. The mobile robot speeds of 0.42, 0.54, 0.66, 0.78, and 0.90 km $h^{-1}$ were approved for determining the amounts of deposits on artificial weeds because the system performed best at these 5 speeds for tracking and spraying accuracies. In the analyses, the amount of tracer on filter papers were determined by the fluorometric method using a spectrofluorophotometer.

The spraying pressure of the system was set to 200 kPa and BSF concentration was 0.4% in tap water. The

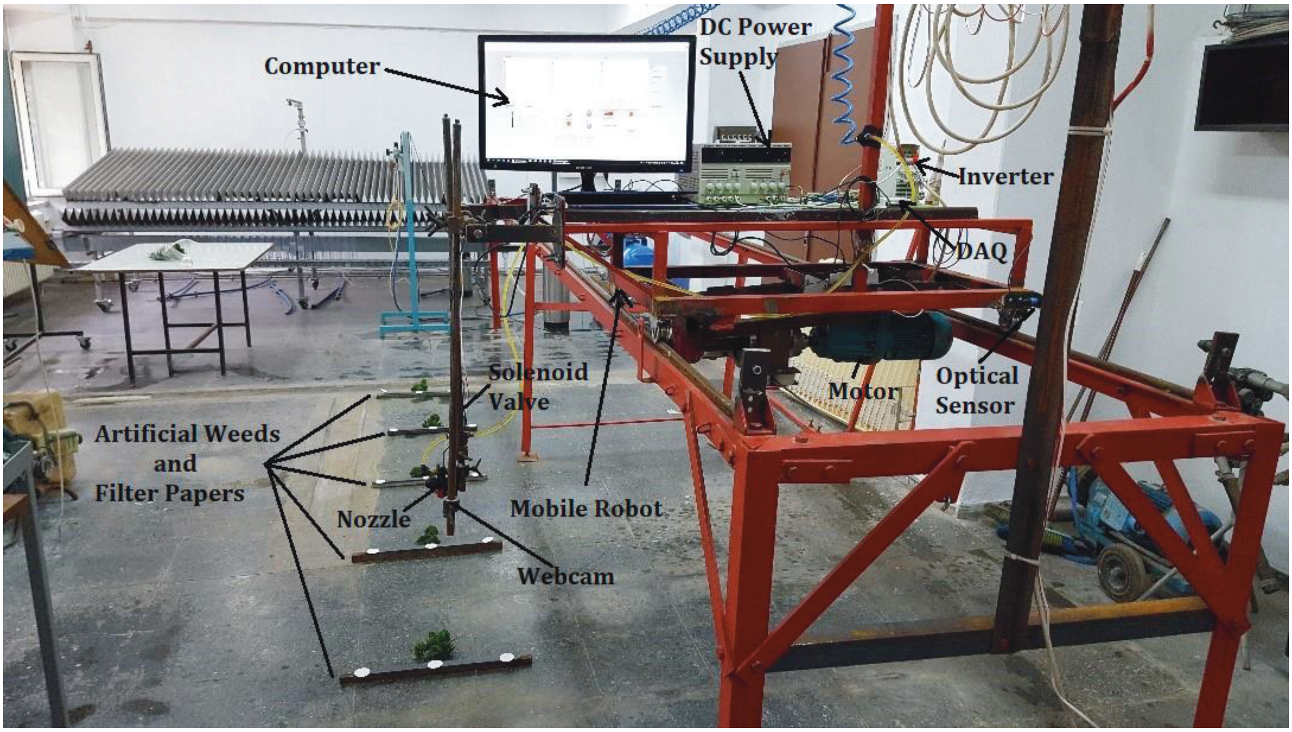


**Figure 3.** Real-time auto tracking and spraying of artificial weed sample in the laboratory.

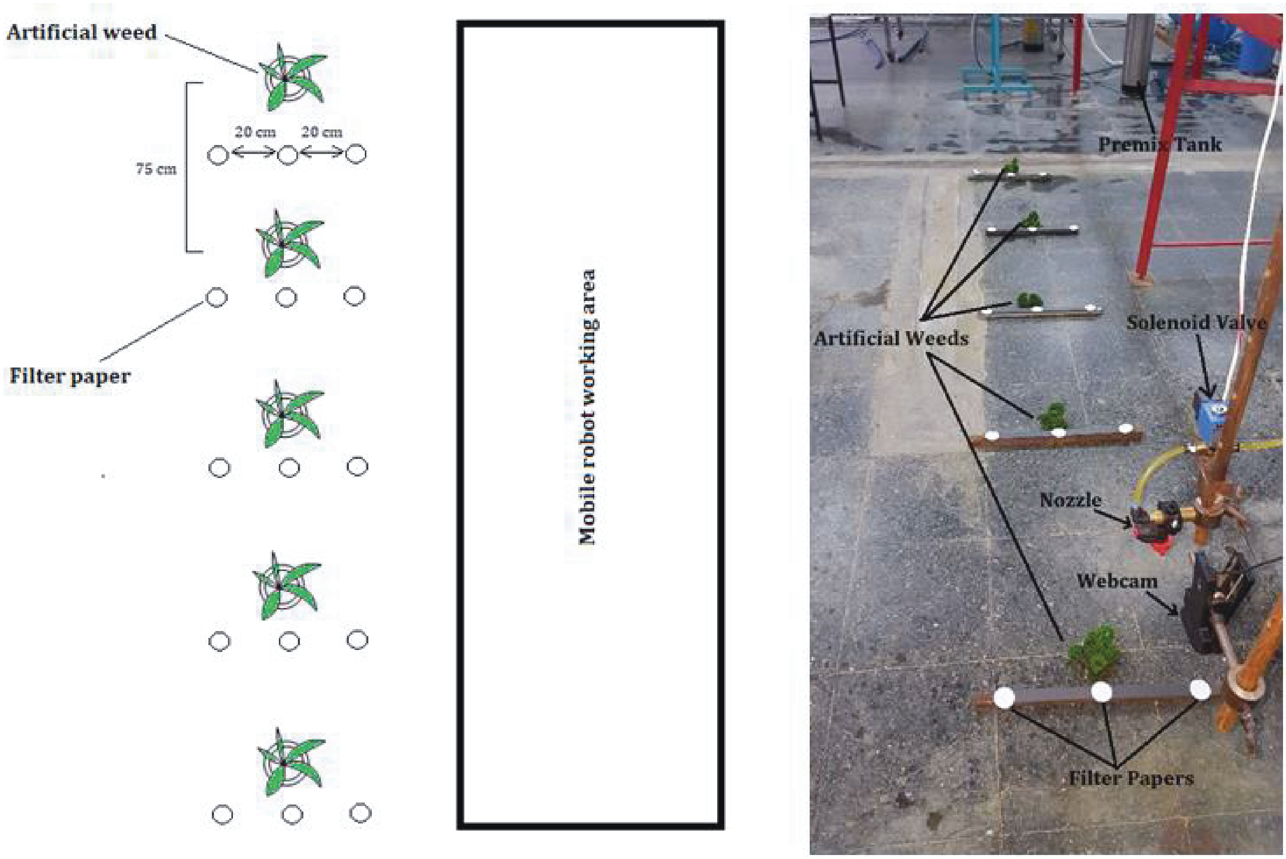


**Figure 4.** Layout of the filter papers.

filter papers were sprayed with BSF trace material in order to determine the deposition profile in the nozzle spray pattern. After the spraying application, target filter papers were collected separately in jars. To measure the amounts of deposits on filter papers in the jars, 20 mL of distilled water was added and each jar was shaken for 10 min. At the end of the process, the samples taken from each glass jar were put into the sample chamber of the spectrofluorophotometer to be analyzed. The excitation and emission wavelengths of the BSF trace material used were 460 nm and 500 nm, respectively. A calibration equation (Equation 4) was achieved with the known BSF concentrations and fluorometric readings. The following equation was a standard equation of BSF material to convert the fluorometric values into real concentrations of samples. A standard curve graph of BSF material is also given in Figure 5.

$$y = 2131{,}21x + 180{,}052$$

$$r^2 = 0{,}99793 \quad (4)$$

While $x$ parameters referred to the concentration value, $y$ parameters referred to the intensity value. The coefficient of determination was denoted as $r^2$.

## 3. Results

### 3.1. Object tracking and image processing performance of the system

The tracking and spraying capabilities of the mobile system were not negatively affected by 0.42, 0.54, 0.66, 0.78, and 0.90 km $h^{-1}$ travel speeds. Real-time auto tracking and spraying capabilities of the mobile system were determined at 100% accuracy level for the 5 speeds at the end of testing. That is, the system has correctly detected and tracked all the samples it has seen at all speeds and performed the spraying process correctly according to their coordinates. If there was no artificial weed to be detected or tracked, the system did not apply any spraying solution. The tracking and spraying capabilities of the mobile system were visually observed. The real-time controller/operator interface established in LabVIEW compiler environment is shown on Figure 6. System software was developed for building a real-time artificial weed tracking application by using LabVIEW and vision acquisition module. Since the mobile system does not have its own braking mechanism, tests for speeds above 0.90 km $h^{-1}$ have not been performed.

### 3.2. Spray volume consumption test results

Laboratory volumetric consumption tests were carried out in order to evaluate the economic impact of the system on volumetric consumption in the eradication of artificial weeds. Site-specific and broadcast spraying methods were compared in the use of spraying liquid. Five artificial weed samples were used and these samples were placed in a single row in succession at 75 cm intervals. Although the mobile system working distance was 6 m, the effective working distance was determined as 4 m. All samples were placed in this active area because the system reached the adjusted speed within 4 m. For each trial, the spraying flow rate of the time controlled solenoid valve was measured as 5.65 mL, 10.75 mL, and 14.00 mL for 500 ms, 1000 ms, and 1500 ms spraying, respectively. The volumetric consumption values of the mobile system are given for site-specific (5 artificial weed samples) and broadcast spraying processes at different speeds in Table 1. The values given in Table 1 are the total amount of liquid (i.e. 10.75 mL/s per plant × 5 artificial plants to be sprayed = 53.75 mL/s) consumed in one trial. As shown in Table 1, the most advantageous spraying process compared with broadcast spraying was site-specific spraying for 500 ms activated spraying nozzle.

By using a pattern check apparatus, the spraying width of the nozzle was measured as 100 cm and optimum working length of the system was determined as 400 cm, as

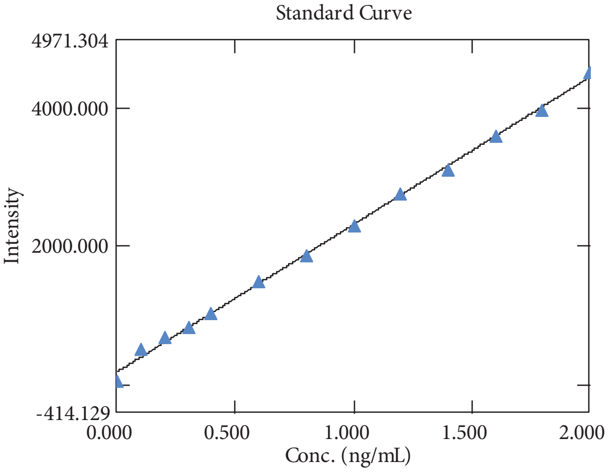
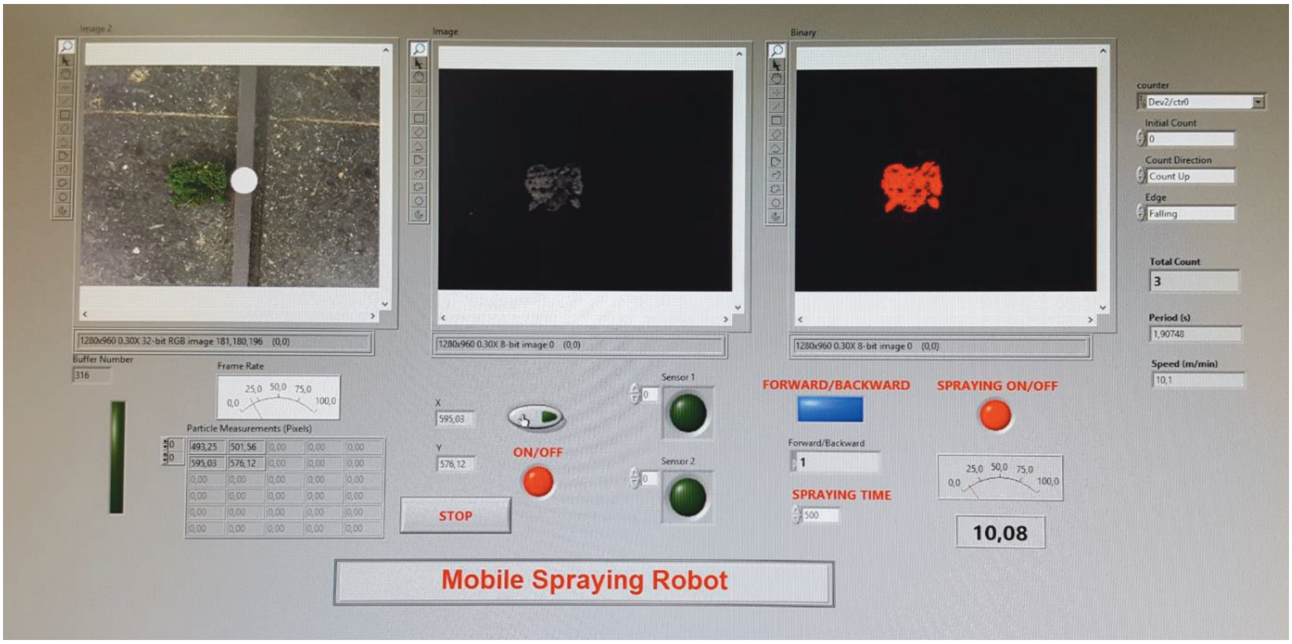


**Figure 5.** Standard curve graph of BSF material.



1280x960 0.30X 32-bit RGB image 181,180,196 (0,0)

1280x960 0.30X 8-bit image 0 (0,0)

1280x960 0.30X 8-bit image 0 (0,0)

Buffer Number 316

Particle Measurements (Pixels)

|  |  |  |  |  |
|---|---|---|---|---|
| 493,25 | 501,56 | 0,00 | 0,00 | 0,00 |
| 595,03 | 576,12 | 0,00 | 0,00 | 0,00 |
| 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |

X 595,03

Y 576,12

Sensor 1 0

Sensor 2 0

Forward/Backward 1

SPRAYING TIME 500

10,08

counter Dev2/ctr0

Initial Count 0

Count Direction Count Up

Edge Falling

Total Count 3

Period (s) 1,90748

Speed (m/min) 10,1

**Figure 6.** Real-time controller/operator interface of a mobile spraying robot.

mentioned before. Thus, the effective spraying area of the mobile robot was calculated as 40,000 cm$^2$ for broadcast spraying. As a result, site-specific spraying (for 500 ms, 1000 ms, and 1500 ms spraying durations) was determined to be more economical than broadcast spraying within the same area for that system. However, this spraying savings changes according to the number of weeds located in the test area. The obtained results showed that travel speed was critical for spraying performance. The spraying performance of the system was affected by factors such as response time delay of the solenoid activated spray nozzle, fluctuations in system pressure based on sudden opening, and closing of the nozzle, etc.

### 3.3. Deposition measurements on artificial weeds

The average deposit concentration results for the mobile robot speeds of 0.42, 0.54, 0.66, 0.78, and 0.90 km h$^{-1}$ are given in Figure 7. As one would expect, the amount of deposits on artificial weeds decreased with increasing spraying speed. Although the spraying pressure of the system did not change, there was a marked reduction in the spraying deposit depending on the speed.

Broadcast spraying method was considered a reference for the amount of deposits on the weeds. As shown in Figure 7, the 1000 ms controlled site-specific spraying process showed the best performance as the deposit concentration is compared with broadcast spraying. Additionally, site-specific spraying accuracies compared with broadcast spraying for the mobile robot speeds of 0.42, 0.54, 0.66, 0.78, and 0.90 km h$^{-1}$ are given in Table 2. The spraying accuracies were also determined by comparing the broadcast spraying as a reference. The broadcast spraying accuracy was accepted as 100%. The site-specific spraying accuracy for 1000 ms activated nozzle also showed better performance among the other nozzles (activated for 500 ms and 1500 ms) as compared with the broadcast spraying accuracy.

Previous studies provided an advantage in herbicide savings, which were between 52% and 79.4%. In this study, the site-specific spraying application saved on average 89.48%, 79.98%, and 73.93% application volumes for 500 ms, 1000 ms, and 1500 ms spraying durations, respectively, for all spraying speeds compared to broadcast spraying application. However, the amount of deposits on the plants has not been considered in those studies. That's why the comparison about the amount of deposits on the plants between the literature and this manuscript could not be presented.

## 3. Discussion

In this study, the automation algorithms integrated mechatronics and image processing for artificial weed detection and site-specific chemical liquid application. A machine consists of vision based, real-time, mobile spraying

**Table 1.** Volumetric consumption values for site-specific and broadcast spraying at different speeds.

| Speed (km h$^{-1}$) | Broadcast spraying (mL) | Site-specific spraying (mL/500 ms) | Site-specific spraying (mL/1000 ms) | Site-specific spraying (mL/1500 ms) | Spraying savings (%/500 ms) | Spraying savings (%/1000 ms) | Spraying savings (%/1500 ms) |
|---|---|---|---|---|---|---|---|
| 0.42 | 377 | 28.25 | 53.75 | 70.00 | 92.51 | 85.74 | 81.43 |
| 0.54 | 313 | 28.25 | 53.75 | 70.00 | 90.97 | 82.83 | 77.64 |
| 0.66 | 265 | 28.25 | 53.75 | 70.00 | 89.34 | 79.72 | 73.58 |
| 0.78 | 236 | 28.25 | 53.75 | 70.00 | 88.03 | 77.22 | 70.34 |
| 0.90 | 210 | 28.25 | 53.75 | 70.00 | 86.55 | 74.40 | 66.67 |
| Average | 280.20 | 28.25 | 53.75 | 70.00 | 89.48 | 79.98 | 73.93 |

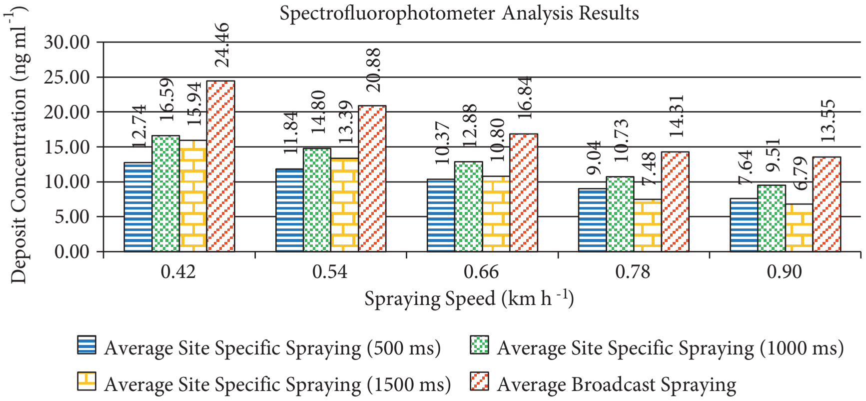


**Figure 7.** Average deposit results of the mobile system at different spraying speeds.

**Table 2.** Site-specific spraying accuracies compared with broadcast spraying accuracy.

| Speed (km h$^{-1}$) | Broadcast spraying* accuracy (%) | Site specific spraying accuracy (%) | | |
|---|---|---|---|---|
| | | 500 ms | 1000 ms | 1500 ms |
| 0.42 | 100 | 52.41 | 67.95 | 65.59 |
| 0.54 | 100 | 57.08 | 71.06 | 64.55 |
| 0.66 | 100 | 61.99 | 76.67 | 64.57 |
| 0.78 | 100 | 63.56 | 75.10 | 52.61 |
| 0.90 | 100 | 56.76 | 70.32 | 50.44 |
| Average | 100 | 58.36 | 72.22 | 59.55 |

* Broadcast spraying was the reference for comparison.

robot was developed and evaluated by using LabVIEW software. The accuracy of the patch spraying performance increased at lower speeds based on laboratory evaluation. The proposed mobile system could successfully detect the weeds and could be used to decrease herbicide quantity. It is obvious that it could provide an economic benefit in the use of herbicides when compared to broadcast spraying method in the eradication of artificial weeds.

The spraying liquid was only applied to artificial weed samples instead of the whole area with the help of the developed system. Real-time, site-specific, and interrow-weed management demonstration was aimed by using the mobile system. Due to the delay in response time of the solenoid activated spray nozzle, the spraying process based on running as on/off with the help of the solenoid valve was inversely proportional to the speed of the mobile robot. The amount of deposits on the artificial weeds changed with forward speed for both methods (site-specific and broadcast spraying methods). Spectrofluorophotometric analysis results showed that although the spraying pressure of the system did not change, there was a marked reduction in spraying deposit depending on the speed. In addition to that, spraying duration of the nozzle also affected the amounts of deposits on artificial weeds.

Such a system will be both environmentally friendly and cost effective. And it could be adaptable to conventional spraying systems if needed. This study will be a model for researchers who aim to work on similar topics, and it will have a positive effect on system design in similar areas.

## Acknowledgement

This work was supported by the Çukurova University Scientific Research Projects Department, Project Number: FBA–2016–6793.

## References

Berenstein R, Edan Y (2018). Automatic adjustable spraying device for site-specific agricultural application. IEEE T Autom Sci Eng 15: 641-650.

Blasco J, Aleixos N, Roger JM, Rabatel G, Molto E (2002). Robotic weed control using machine vision. Biosyst Eng 83: 149-157.

Gonzalez-de-Soto M, Emmi L, Perez-Ruiz M, Aguera J, Gonzalez-de-Santos P (2016). Autonomous systems for precise spraying – evaluation of a robotised patch sprayer. Biosyst Eng 146: 165-182.

Gonzalez RC, Woods RE (2008). Digital Image Processing. 3rd ed. Pearson International Edition, USA: Prentice Hall.

Jafari A, Mohtasebi SS, Jahromi HE, Omid M (2006a). Weed detection in sugar beet fields using machine vision. International Journal of Agriculture and Biology 8: 602-605.

Jafari A, Mohtasebi SS, Jahromi HE, Omid M (2006b). Color segmentation scheme for classifying weeds from sugar beet using machine vision. Iranian Journal of Information Science and Technology 4: 1-12.

Loghavi M, Mackvandi BB (2008). Development of a target oriented weed control system. Comput Electron Agr 63: 112-118.

Loni R, Loghavi M, Jafari A (2014). Design, development and evaluation of targeted discrete-flame weeding for inter-row weed control using machine vision. American Journal of Agricultural Science and Technology 2: 17-30.

Perez AJ, Lopez F, Benlloch JV, Christensen S (2000). Colour and shape analysis techniques for weed detection in cereal fields. Comput Electron Agr 25: 197-212.

Sabancı K, Aydın C (2014). Image processing based precision spraying robot. Journal of Agricultural Sciences 20: 406-414.

Sabancı K, Aydın C (2017). Smart robotic weed control system for sugar beet. J Agric Sci Technol 19: 73-83.

Shirzadifar AM, Loghavi M, Raoufat MH (2013). Development and evaluation of a real time site-specific inter-row weed management system. Iran Agricultural Research 32: 39-54.

Slaughter DC, Giles DK, Downey D (2008). Autonomous robotic weed control systems: A review. Comput Electron Agr 61: 63-78.

Tangwongkit R, Salokhe VM, Jayasuriya HPW (2006). Development of a real-time, variable rate herbicide applicator using machine vision for between-row weeding of sugarcane fields. Agricultural Engineering International: The CIGR Ejournal 8: 1-12.

Tellaeche A, Burgos-Artizzub XP, Pajaresa G, Ribeirob A (2008). A vision-based method for weeds identification through the bayesian decision theory. Pattern Recognition Society 41: 521-530.

Tian L (2002). Development of a sensor-based precision herbicide application system. Comput Electron Agr 36: 133-149.

Tillett ND, Hague T, Miles SJ (2002). Inter-row vision guidance for mechanical weed control in sugar beet. Comput Electron Agr 33: 163-177.

Timmermann C, Gerhads R, Kühbauch W (2003). The economic impact of site-specific weed control. Precis Agric 4: 249-260.

Wan Ishak WI, Abdul Rahman K (2010). Software development for real-time weed colour analysis. Pertanika Journal of Science and Technology 18: 243-253.

Xue J, Zhang L, Grift TE (2012). Variable field-of-view machine vision based row guidance of an agricultural robot. Comput Electron Agr 84: 85-91.

Yang C, Prasher SO, Landry J, Kok R (2002). A vegetation localization algorithm for precision farming. Biosyst Eng 81: 137-146.

Yang C, Prasher SO, Landry J, Ramaswamy HS (2003). Development of an image processing system and a fuzzy algorithm for site-specific herbicide applications. Precis Agric 4: 5-18.

Zhou H, Wu J, Zhang J (2010). Digital Image Processing – Part I. Ventus Publishing ApS.