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# DETERMINATION OF SPRAY ANGLE IN SPRAYER NOZZLES USING COMPUTER VISION TECHNIQUE

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**ABSTRACT**
Before the pesticide applications with sprayers, the flow rates of the spray nozzles should be controlled, and the flow rate uniformity of the spraying should be checked in the calibration processes. Irregular flow in the sprayer nozzles causes deterioration of the spray pattern and the volumetric distribution uniformity. Production errors in the orifice geometry of the hydraulic nozzle used in sprayers, wear due to long-term use, tearing or cracking of the nozzle body over time, faulty nozzle connections and sealing problems can be listed as structural factors disrupting spray angle and pattern. The aim of this research is to develop a measurement system and software that controls nozzle spray angle in real time in addition to the measurement and control systems currently used to perform flow controls in sprayer nozzles. The measurement system consists of light apparatus and camera. In the software creation, it is aimed to determine the spray angle online through the real-time flow images. The angle values determined on a standard basis can be viewed on the control screen and various statistics can be obtained from the images taken online with the camera. According to preliminary results, the spray angle measurement system and software can be used efficiently and practically in research, production and development studies, measurement and control laboratories and hydraulic nozzle flow tests.

***Keywords:*** *Hydraulic nozzle, Image processing, Sprayer, Spray pattern*

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## 1. INTRODUCTION

The fastest and most effective method against diseases and pests that harm the culture plants is the chemical method, which makes it necessary to use powder or liquid chemicals called pesticides. Most of the applications are carried out with equipment called sprayers equipped with hydraulic pump. The chemicals prepared by diluted in the liquid form in the tank are sprayed under the influence of hydraulic pressure and transmitted to the target in drops. The preparation of a particular concentration prepared in a homogeneous manner during spraying ensures that the effective substance reaches the same dosage to all surfaces and thus increases the expected success of the chemical control. The uniformly transport of the chemical to the target, which is broken into drops, varies depending on the type of hydraulic nozzle, operating pressure, spray height, application speed and meteorological factors (Hoffmann and Salyani, 1996; Panneton *et al*., 2000; Zhu *et al*., 2002; Zhu *et al*., 2004; Bayat and Bozdoğan, 2005).

In order to uniformly transport of the drops set leaving the orifice in a given distribution pattern, it is necessary to provide sufficient coating on the surface by overlapping at a certain height. The coating rate required for this is dependent on the spray height, which is determined by the spray angle of the hydraulic nozzle. For conventional spray applications, the minimum spray heights recommended for 65º, 80º, 110º and 120º nozzles were reported to be 75, 60, 40 and 40 cm, respectively (Teejet®, 2016). Narrow angled spray nozzles are recommended to be used in banded applications for plants planted in rows, but are preferred to increase drop penetration in tall plants (Matthews and Thornhill, 1994; Matthews, 2004). However, increasing the spray height as the spray angle decreases can cause the droplets to evaporate by the effect of temperature and humidity, turbulence with wind speed and reverse air currents, leading to increased pesticide consumption and losses (Dursun *et al*., 2000). As the spray angle varies depending on the design of the outlet orifice in the hydraulic nozzles, at the same spray pressure, the liquid strip leaving the orifice becomes thinner and the resistance to disintegration decreases and finer droplets occurs. As the height of such nozzles increases, the energy of transporting the drug drops to the target decreases and thus drug losses increase due to evaporation and drift. Therefore, in order to reduce drag on nozzles with a wide spray angle, the spray distance must be reduced. For these reasons, there is a general tendency in the choice of nozzle to use sprayer nozzles with a larger spray angle (Matthews, 2004).

Spray pattern and flow uniformity tests related to hydraulic nozzles used in sprayers are carried out on measuring tables called patternators. It was reported that the volumetric distribution was acceptable for the 15% variation and the distribution for the 10% variation was quite homogeneous (Bode *et al*., 1983; Azimi *et al*., 1985; Krishnan *et al*., 1988). The measurements and tests performed on hydraulic nozzles reveal the operating characteristics (height, pressure, mounting range, position angle, etc.) required for uniform pesticide applications. In addition, flow tests reveal production errors in the nozzle orifice geometry, wear caused by long-term use, tearing or cracking of the nozzle body over time, faulty nozzle connections and sealing problems. These factors, which disrupt the flow uniformity, often cause deviations in the spray angle of the hydraulic nozzle. This appears to be detectable with control equipment which measures the spray angle in a practical way.

There is no standard method used in practice for determining the spray angle. In the present case, protractors are used in practice or can be measured by means of image processing software via spray images. However, this process takes time as well as the contours of the angle on the image are determined by the operator's personal preference. Determination of the spray angle on a standard basis is of great importance for the accuracy and practicality of the measurements. The aim of this study is to develop a new measurement system and software that can calculate, record and calculate spray angle values online through flow images of sprayer nozzles in laboratory conditions.

## 2. MATERIAL AND METHOD

Computer vision is an interdisciplinary field that enables us to evaluate and make useful decisions about the environment through digital images of the environment of interest (Aslantaş and Toprak, 2017). Calculation of the spray angle on the spray images by computer vision techniques will make this process objective by removing the operator's initiative. This section provides details of the system and software developed for calculating the nozzle spray angle in the laboratory using computer vision techniques. In addition, the spray angle calculation method used in the developed software is introduced.

### 2.1. Image Acquisition System

In order to determine the spray angle variation during spray application, it is aimed to develop an application in which spray angle is calculated instantly in spray nozzles displayed in the laboratory condition. In the system, the images obtained through a camera in the laboratory condition are transferred to the developed software. With the application developed, both the current spray image and the spray angle are presented to the user. The operation of the system designed for calculating the spray angle of the sprayer nozzle is shown in Figure 1.

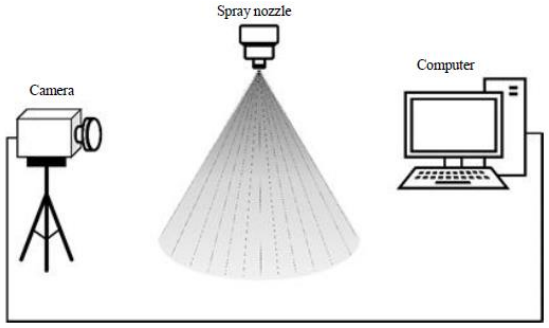


Fig. 1. System diagram for measuring the spray angle of a spray nozzle in a laboratory

The Nikon D300 DSLR camera is used for spraying images. The camera was placed on a tripod to stabilize the images. To achieve high contrast images, a black

background was placed on the background of the spray boom, and two paraflashes are again positioned behind the spray boom. To improve the quality of the spray image, the floor-mounted lighting device is arranged to illuminate the output of the flow beam.

## 2.2. Application of Spray Angle Measurement

The spray angle measurement application is intended to enable the user to instantly display the spray image and calculated spray angle value of a sprayer nozzle in the laboratory with an easy to use and interactive interface. In the development of the software, Python programming language has been preferred in order to be able to design the interface easily and to perform visual operations with the computer. A spray image and an angle value representation on the interface is shown in Figure 2.

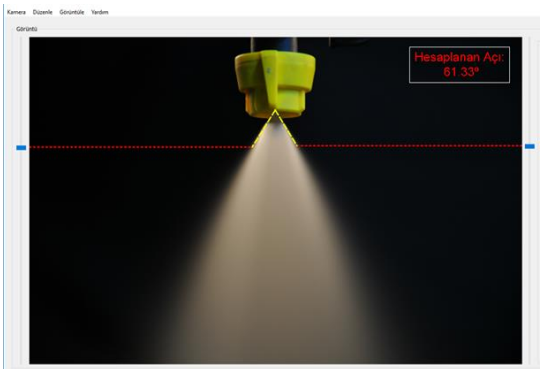


Fig. 2. Interface of spray angle measurement application

The spray angle calculation starts with the acquisition of the spray image from the camera. To do this, the user must first select the start option from the camera drop-down list in the top menu. When the user clicks the start tab, a connection is established between the camera and the software defined in the system and the system is ready to receive the image. The camera drop-down list also includes the pause and stop options for pausing and turning off the camera.

The display tab in the top menu of the main screen also includes the take-up and start analysis tabs, in which the user can perform image acquisition from the camera and calculate the angle value, respectively. When the user clicks on the take image command, the image of the scene displayed by the camera defined in the system is captured and shown to the user on the interface. When the user clicks the start analysis command again under the view menu, the recorded image is analysed in the following section with the method detailed and the spray angle is calculated and presented to the user on the interface.

If the positions of the points used by the operator to calculate the angle in the spray angle calculation process are not selected appropriately, the spray angle may be calculated incorrectly. In order to accurately calculate the spraying angles of sprayer nozzles of different types and pressures, it is expected that the lines where the right and left edge points will be searched on the image will be determined interactively by the user. For this purpose, the user can determine the lines through which the right and left switch points are searched by means of the slider bars on both sides of the spray image received from the camera. The user must specify the process of determining the lines on which the analysis is to be performed before starting the analysis.

Spray images to calculate the spray angle can be refreshed at any time using the take image command. The user should start the process of calculating the angle again with the start analysis command for each image taken from the camera.

## 2.3. Spray Angle Calculation Method

Three key points, right, left and top, are used to calculate the spray angle on the spray image from the camera. The first step of the spray angle calculation process is to determine the right and left key points on the user-specified lines. The points where the sprayed liquid starts and ends on the user-specified line should be determined as left and right key points. Since the user does not have sufficient information about the constantly changing images, a manual angle calculation will not give the desired result in all cases. Therefore, in the developed application, a method has been proposed which allows the automatic finding of the right and left key points. The proposed method requires user-defined lines to calculate points.

The right and left key points are located on the boundary between the area covered by the sprayed liquid and the background area in the user-specified line. This boundary line corresponds to the points at which the intensity change occurs in the respective lines. From this perspective, if images are divided into spray and background zones, the right and left switch points can be specified as the transition between the background and spray zone. Automatic thresholding methods can be used to determine this transition.

One of the most common and successful automatic thresholding functions is the Otsu method (Otsu, 1979). The herbaceous automatic thresholding method works with the assumption that the image consists of pixels that fall into two classes, foreground and background. Iteratively investigates the minimized threshold value of the in-class variances of the obtained classes and the value is found as the optimal threshold value. In-class variance is found by Eq. (1) as the weighted sum of the variance values of the two classes:

$$\boldsymbol{\sigma_{si}^2 = \omega_0(t)\sigma_0^2(t) + \omega_1(t)\sigma_1^2(t)} \quad (1)$$

here $\omega_0$ and $\omega_1$ are the probability values of the two classes separated by the threshold value $t$, and $\sigma_0^2$ and $\sigma_1^2$ are the variance values of these classes. Minimizing in-class variance is equal to maximizing inter-class variance. Since the calculation of variance between classes brings less processing load, Eq. (2) preferred to find the optimum threshold value:

$$\boldsymbol{\sigma_{sa}^2 = \sigma^2 - \sigma_{si}^2(t) = \omega_0(\mu_0 - \mu_T)^2 + \omega_1(\mu_1 - \mu_T)^2} \quad (2)$$

where $\mu_0$ and $\mu_1$ are the means of the two classes, and $\mu_T$ is the mean of the entire grey-level image. As given by Eq. (3), the Otsu method determines the threshold value that will maximize the differences between the classes as the optimum threshold value:

$$\boldsymbol{t_{opt} = arg\ max\{\sigma_{sa}^2(t)\}} \quad (3)$$

After applying the Otsu threshold value method to the user-selected lines, the pixel at which the transition from the spray zone to the background on the black and white image of that line is determined as the key point.

After the right and left points obtained by the Otsu threshold determination method, the end point required for the calculation of the spray angle should be determined. This third point is the peak, the starting point of the sprayed liquid. This point cannot be detected directly since it remains essentially within the sprayer nozzle and cannot be imaged. However, it can be estimated approximately using the spray zone. In order to estimate the peak, the curves forming the boundaries of the spray zone need to be known.

In order to find the peak, the spraying image is first replaced by pixels 1 higher than a certain threshold value and pixels with low intensity 0, resulting in a binary (black and white) image. The above mentioned Otsu method is used to find the threshold value. However, the resulting dual image may include the spraying zone as well as the spray nozzle and different objects. Since only the spray zone is needed to locate the peak, only the spray zone must be removed first on the binary image. Therefore, the linked regions are determined by applying component analysis based on binary image. The linked component analysis operator scans the binary image pixel by pixel to identify adjacent pixel regions that share the same intensity value. The largest of the zones obtained as a result of this process is determined as the spray zone.

The peak may be defined as the intersection of two curves forming the edges of the spray zone. The pixels forming the right and left edges of the spray area are found and their horizontal and vertical coordinate values are recorded. The polynomial is best defined by the curve fitting method using the coordinates of the points that make up the left and right sides. Curve fitting is defined as finding an appropriate curve or the right equation to reflect the pattern of the relationship between the two variables (Guest, 2012). Within the scope of the paper, there are two functions of the 3rd order using points expressing the right and left edges. If the polynomials expressing the left and right edges are considered *f(x)* and *p(x)* respectively, the intersection point of these polynomials is found by the exit point of the sprayed liquid, in other words, the peak point (*T*) by Eq. (4):

$$\boldsymbol{T} = \boldsymbol{f}(\boldsymbol{x}) \cap \boldsymbol{p}(\boldsymbol{x}). \tag{4}$$

The spray angle can then be calculated using these three points found after this step. The vertex, left margin and right margin are defined as T, A and B respectively. The vectors between the vertex and edge points are defined in Eq. 5.

$$\begin{aligned} \overrightarrow{\boldsymbol{TA}} &= \boldsymbol{A} - \boldsymbol{T}, \\ \overrightarrow{\boldsymbol{TB}} &= \boldsymbol{B} - \boldsymbol{T}. \end{aligned} \tag{5}$$

In this case, since the points T, A and B are known, the angle (θ) between the two vectors can be calculated by Eq. (6).

$$\boldsymbol{\theta} = \boldsymbol{arccos}\left(\frac{\overrightarrow{\boldsymbol{TA}} \cdot \overrightarrow{\boldsymbol{TB}}}{\|\overrightarrow{\boldsymbol{TA}}\|\|\overrightarrow{\boldsymbol{TB}}\|}\right), \tag{6}$$

here || || refers to the length of the vector.

## 3. RESULTS

In order to investigate the performance of the proposed method, the spray angle values calculated on the instant spray images were compared with the angle values found by the expert using the image processing methods on the same images. The spray angle at the nozzle orifice outlet was determined by the operator using the angle module of the ImageJ v.1.38x (Wayne Rasband, National Institutes of Health, US) image processing software on the obtained high contrast fixed images (Abràmoff *et al*., 2004). Images were taken at three different spray pressures (200, 400 and 600 kPa) on disc-core type hollow cone nozzles made of stainless steel (Cr-Ni) with orifice diameter 1.0 mm and 1.5 mm. In repetitive studies, five different nozzle discs taken from the same diameter group by chance were used.

Table 1 shows the results from the orifice diameter 1.0 mm nozzle disc. When the results were examined, the average of the angles measured by the operator by image processing technique were measured as 41.77º, 53.77º and 59.83º for 200, 400 and 600 kPa, respectively. The angle values measured by the spray angle calculation software were 40.80º, 57.77º and 62.04º. Accordingly, the spray angle provided very close results in both methods.

Table 1. Spray angle (º) values in hollow cone nozzle with orifice diameter 1.0 mm

| Nozzle discs | Image processing technique | | | Spray angle software | | |
|---|---|---|---|---|---|---|
| | Pressure (kPa) | | | Pressure (kPa) | | |
| | 200 | 400 | 600 | 200 | 400 | 600 |
| 1 | 43.09 | 56.17 | 62.26 | 42.90 | 58.49 | 63.65 |
| 2 | 40.27 | 55.74 | 61.67 | 40.65 | 60.51 | 63.36 |
| 3 | 44.70 | 53.09 | 56.84 | 43.50 | 58.00 | 59.53 |
| 4 | 40.59 | 51.20 | 58.22 | 40.53 | 55.67 | 60.20 |
| 5 | 40.20 | 52.67 | 60.16 | 36.43 | 56.17 | 63.44 |
| Mean | 41.77 | 53.77 | 59.83 | 40.80 | 57.77 | 62.04 |
| SD* | 2.03 | 2.12 | 2.29 | 2.78 | 1.94 | 2.00 |

*: standard deviation

The spray angle values determined by image processing technique and spray angle calculation software in hollow cone nozzle disc with orifice diameter 1.5 mm were compared in Table 2. The average spray angle values varied from 69.85º to 84.15º in image processing at 400 kPa spray pressure, and between 69.88º and 78.34º in the software. When the image processing technique and the spray angle calculation software are compared, it is generally found that all spray angle values overlap with each other.

Table 2. Spray angle (º) values in hollow cone nozzle disc with orifice diameter 1.5 mm

| Nozzle discs | Image processing technique | | | Spray angle software | | |
|---|---|---|---|---|---|---|
| | Pressure (kPa) | | | Pressure (kPa) | | |
| | 200 | 400 | 600 | 200 | 400 | 600 |
| 1 | 67.97 | 79.95 | 76.49 | 67.71 | 78.51 | 78.17 |
| 2 | 71.65 | 84.15 | 88.84 | 75.06 | 78.34 | 83.45 |
| 3 | 66.15 | 69.85 | 68.36 | 72.16 | 69.88 | 74.57 |
| 4 | 65.40 | 76.06 | 77.54 | 64.18 | 75.32 | 78.02 |
| 5 | 66.74 | 72.09 | 71.52 | 67.72 | 74.24 | 75.39 |
| Mean | 67.58 | 76.42 | 76.55 | 69.37 | 75.26 | 77.92 |
| SD* | 2.46 | 5.79 | 7.82 | 4.26 | 3.54 | 3.47 |

*: standard deviation

The proposed method has 0.1379 seconds processing time for 1072×712 source images on a computer with AMD FX-8350 4Ghz processor and 16GB main memory. This result is much shorter than the time required for an expert to analyse the image, place the dots on the images, and determine the angle.

## 4. CONCLUSION

Hollow cone nozzle discs with different orifice diameters were used in the study and spray angle changes were compared with two different methods at three different operating pressures. When the measurement method is evaluated, it is observed that the flow contours that allow the determination of the spray angle on the images can vary from user to user, and the time taken in the measurements is higher than the newly developed application. With the developed spray angle detection method, no operator experience is required, it is observed that the spray angle can be determined on a standard basis thanks to the easy-to-use and interactive interface, and the spray angle values can be observed instantly on the control screen depending on time. As a result of the research, it was determined that the spray angle values determined by two different measurement methods matched at a high rate and the developed software showed successful results.

The spray angle calculation method proposed within the scope of this study is able to calculate on single images taken in the laboratory. In future studies, it is planned to introduce a more practical and modular new software that can detect spray angle in real time on continuous images.

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