Quantitative Assessment of UAV Assisted Particle Spraying Distribution in Agriculture: An Image Analysis Approach Using Water-Sensitive Papers

Original Scientific Paper

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Abstract *– The overall well-being and productivity of crops rely on a series of interconnected processes throughout their entire growth cycle. Among these processes, the quality of spraying plays a pivotal role in maintaining crop health and ensuring increased productivity. An Unmanned Aerial Vehicles assisted particle spraying system in agriculture involves the use of Unmanned Aerial Vehicles equipped with specialized equipment to distribute particles such as plant protection products, fertilizers, or other agricultural inputs over crops. This technology offers several advantages over traditional ground-based methods, including increased efficiency, precision, and reduced environmental impact. The effectiveness of spraying, in turn, hinges on various factors, one of which is the even distribution of spraying droplets. Consequently, there exists a need for a reliable, consistent, precise, and accurate automated method to assess the parameters governing this distribution. In this study, a methodology is introduced for evaluating the quality of plant spraying, and the results of this method's testing are presented. Data is gathered by employing water-sensitive papers positioned on the crops, which are then scanned using an industrial-grade camera. Subsequently, this data undergoes processing through image analysis algorithms using Matlab. The outcomes of the research demonstrate the robustness of the proposed methodology in obtaining the essential data required for determining spraying distribution. Compared to existing solutions, the presented approach offers increased reliability, consistency, precision, and automation, thereby addressing the need for a more reliable and accurate method of assessing spraying quality in agriculture.*

Keywords*:* *Droplet segmentation, Spray quality, Computer simulation, UAV (Unmanned Aerial Vehicle), Water-sensitive papers (WSP)*

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1. INTRODUCTION

In this paper, the examination and confirmation of a method for inspecting the quality of plant spraying was conducted. More specifically, the research focused on determining the occurrence of droplets on liquid-reactive papers during spraying. Based on this, methods for measuring droplets, mapping the dispersion of spray and the study of the density, size, and distribution of droplets on paper were investigated and established.

Numerous methods have been devised for plant spraying to enhance the growth of specific plant types and eradicate unwanted weeds. Also, different investigations were conducted with the aim of gaining insights into the effectiveness and characteristics of plant spraying techniques. Also, in recent years, Unmanned Aerial Vehicle (UAV) path planning and spraying droplet analysis were introduced that are essential components of modern precision agriculture practices. By optimizing coverage, minimizing environmental impact, and providing valuable data for decision-making, these processes have contributed to sustainable and efficient plant protection products (PPP) application in agriculture. Accurate path planning and droplet analysis has helped to ensure compliance with regulatory requirements for PPP application. By demonstrating uniform coverage and minimal drift, farmers can provide evidence of responsible PPP use and mitigate potential regulatory risks. Efficient path planning helps optimize resource usage, including PPP, fuel, and time. By following a predetermined flight path, UAVs can avoid unnecessary overlap and reduce the amount of PPP required to achieve adequate coverage. This not only saves costs but also minimizes environmental impact by reducing chemical usage. Properly measuring the quality of spraying helps maintain crop health and maximize productivity. By ensuring that the spray is evenly distributed and properly targeted, it effectively controls pests and diseases, resulting in healthier plants and improved yields. Due to the rapid development of our world and the continuous growth of the population, there is a need to increase food and grain production. Building upon this, it is essential to engage in the spraying of plants and continually monitor and enhance the process. The use of PPP has to be channeled in such a way that there is no waste, thereby avoiding environmental pollution. When using the sprays, the outside wind can act as a disturbance, so the given spray is not sprayed on the desired area. Based on this, more PPP is needed [1]. Agricultural spraying methods encompass various techniques and equipment used to apply agricultural chemicals, including PPP, herbicides, fungicides, and fertilizers, to crops for protection against pests, diseases, and weeds, as well as to provide essential nutrients. The most used spraying methods are:

- Backpack Sprayers: Backpack sprayers are manually carried/transported, and they are suitable for smaller areas or limited access [2].
- Boom Sprayers: Mounted on tractors or specialized sprayer vehicles, equipped with a tank, pump, and a boom structure with multiple spray nozzles for efficient coverage over larger areas [3].
- Airblast Sprayers: Utilize high-velocity air streams to propel spray droplets for precise targeting mainly in orchards and vineyards [4]. By harnessing powerful air streams, airblast sprayers can penetrate deep into the crop canopy, ensuring thorough coverage and effective pest and disease control. This high-rate application capability makes airblast sprayers a popular choice for growers seeking to maximize spraying efficiency and optimize crop protection.
- Aerial Spraying: Involves using aircraft, such as helicopters or fixed-wing planes, to apply sprays over large areas or challenging terrains. These days UAVs are also taking part in aerial spraying [5, 6].
- Drip Irrigation and Fertigation: Systems delivering water, fertilizers, and chemicals directly to the root zone of plants through a network of pipes with emitters [7].

Air-assisted spraying is a spraying technique that combines the use of liquid sprays and high-velocity air to improve the coverage and penetration of the spray droplets. In this method, a spray solution is atomized into fine droplets, and then a powerful air stream is used to carry and disperse the droplets effectively. Air-assisted spraying offers several advantages in agricultural applications:

- Enhanced Coverage: The high-velocity air assists in breaking down the spray solution into smaller droplets, which can result in improved coverage of the target surface, such as plant foliage. This is particularly beneficial for achieving better coverage in dense crops or complex plant structures.
- Increased Penetration: The air stream created by the sprayer helps propel the droplets deeper into the crop canopy, ensuring better penetration into the target area. This can be advantageous when targeting pests or diseases residing within the foliage.
- Reduced Drift: The use of air assistance in spraying can help minimize drift, which refers to the movement of spray particles away from the target area. By generating larger droplets and directing them with controlled airflow, air-assisted spraying reduces the risk of off-target deposition.
- Improved Efficiency: The combination of atomization and air assistance allows for more precise application of agricultural chemicals, resulting in reduced chemical usage and potential cost savings. Additionally, the improved coverage and penetration can enhance the effectiveness of the applied products [8, 9].
- Optimized Droplet Size: UAVs can be equipped with nozzles that produce droplets of an optimal size for the specific application, reducing evaporation and drift. Smaller, uniformly sized droplets are more likely to adhere to plant surfaces, improving the effectiveness of the pesticide.
- Lower Fuel Consumption: UAVs are generally more fuel-efficient compared to traditional ground-based vehicles like tractors or self-propelled sprayers. This efficiency translates to lower carbon emissions and a reduced environmental footprint.
- Resource Efficiency: By using precise application techniques, UAVs help conserve resources such as water and pesticides. This efficiency not only lowers costs but also minimizes the environmental impact associated with the production and transport of these resources.
- Environmental Monitoring: UAVs can be equipped with sensors to monitor environmental conditions in real-time, adjusting spraying parameters as needed to account for wind speed, humidity, and temperature. This adaptive approach further reduces waste and environmental impact by ensuring that spraying is conducted under optimal conditions.

Air-assisted spraying is commonly used in orchards, vineyards, and other specialty crops where precise targeting and thorough coverage are important. It requires specialized sprayer equipment that includes air blowers or fans to create the necessary air stream and atomizers to generate fine droplets [10-12]. The specific recommendations for air-assisted spraying techniques may vary depending on the target crop, spray solution, and local regulations. It's essential to follow manufacturer guidelines and consult relevant agricultural resources or experts for proper application techniques and equipment calibration [13]. On the other hand, the conventional methods are promising too, even if some other methods, like air-assisted methods, can provide several advantages. Inappropriate spraying methods, or equipment used for application can cause health issues for people. When working with PPP-s, or other chemicals, the missing calibrations or regulations can affect the quality of spraying and can result in off-target spraying that is unfortunate [14]. UAVs equipped with advanced GPS and sensors can follow precise flight paths, ensuring that PPP-s are applied only where needed. This precision reduces the amount of pesticide used by avoiding unnecessary overlap and targeting specific areas that require treatment. UAVs can be equipped with nozzles that produce droplets of an optimal size for the specific application, reducing evaporation and drift. Smaller, uniformly sized droplets are more likely to adhere to the plant surfaces, improving the effectiveness of the PPP-s.

The need for quality check and way to collect data is briefly described in the paper [15]. That work provided a system that required several portable elements that were working simultaneously. The new method presented in this paper is a novelty and the main difference between other solutions lies in the use of a more compact data collecting unit and an industry-ready high-quality camera. The proposed method used in this research is presented in Fig. 1.

Fig. 1 presents the steps during the process. The proposed methodology and the equipment that was used, as well as the results are described in the following chapters. The current methods for measuring the properties of sprayed droplets suffer from limitations such as being manual, imprecise, or expensive. Traditional approaches involve spraying colored water onto a white sheet or using a "patternator" and then analyzing the resulting patterns to estimate droplet sizes, but these methods provide only rough estimations. Alternatively, a more refined technique involves replacing the white sheet with a glass plate coated with silicone oil, known as the immersion sampling method. Nevertheless, accurately determining of the droplets' characteristics remains a significant challenge in precision agriculture. Addressing this aspect is crucial for a comprehensive understanding of droplet behavior during spraying operations.

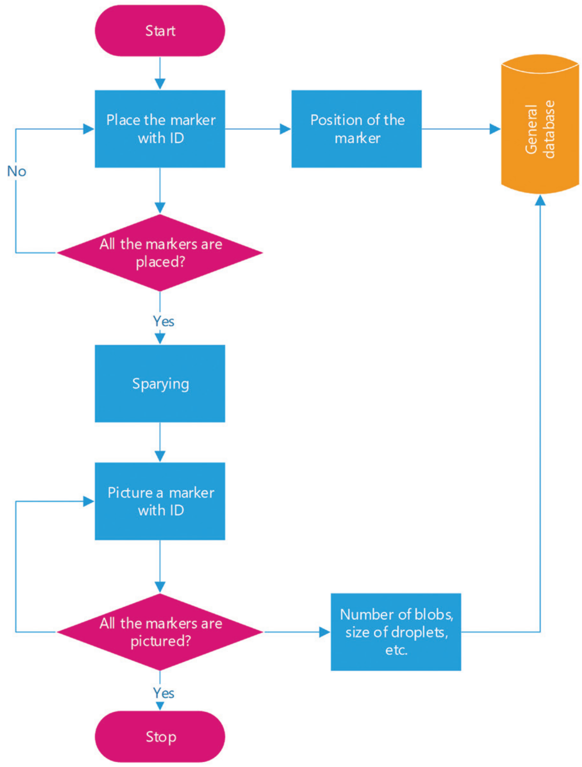


Fig. 1. Method of gathering on-site data

Future advancements in measurement techniques, such as the proposed method, are needed to overcome these limitations and enhance the precision and efficiency of agricultural spraying practices [16]. In this paper, significant contributions are made to the field of agricultural spraying by addressing the critical need for reliable and precise methods of assessing spray quality. Specifically, a methodology for evaluating the quality of plant spraying is examined and confirmed, with particular emphasis placed on detecting droplets on liquid-reactive papers during spraying. The contributions of this paper can be summarized as follows:

- A comprehensive methodology is introduced, encompassing various aspects of assessing spray quality, including methods for measuring droplets, mapping spray dispersion, understanding the importance of quality assessment, and studying droplet density, size, and distribution on paper.
- Integration of Advanced Technologies such as UAV path planning and spraying droplet analysis are leveraged to enhance precision, efficiency, and environmental sustainability in agricultural spraying practices.
- A novel approach for data collection is introduced, utilizing water-sensitive papers positioned on crops and scanned using an industrial-grade camera. This approach enables automated data collection and processing, enhancing accuracy and reliability.
- By providing insights into the effectiveness and characteristics of plant spraying techniques, this study contributes to the advancement of preci-

sion agriculture practices, ultimately leading to improved crop health and productivity.

By addressing the limitations of existing techniques and leveraging cutting-edge technologies, the methodology provided in this paper serves as a valuable tool for farmers, researchers, and practitioners seeking to optimize spraying operations and minimize environmental impact.

2. RELATED WORK

In [1], an analysis of the spray drift mechanism and the primary factors influencing aerial spraying was conducted, and previous research on Drift Reducing Technologies (DRT) in aerial spraying was reviewed and summarized. It was found that DRT-s in aerial spraying, such as aerial electrostatic spray technology, aerial spray adjuvant, aerial air-assisted spray technology, drift reducing nozzles, and aerial variable-rate spray technology, can effectively reduce environmental pollution caused by PPP drift by decreasing the spraying amount and improving the control effect of PPP. The exact methodology and equipment are required in every spraying application, whether it is from the air or from the ground. From [2], it can be concluded that calibration is vital, and there are rarely overall results that can be used with complete confidence for every sprayer.

When time and energy play a major role in the process, optimal methods should be applied. Some methods are faster than others and are easier to replicate, just like the DEIAFA method from [3]. This work shows that every workflow should be overviewed before deciding to use one. The study presented in [4] proposes an alternative indirect methodology for the comparative measurements of drift reduction potential generated by airblast sprayers, aimed at addressing the practical inconveniences and drawbacks. In [5], precision aerial application for site-specific crop management is discussed, with an examination of several current trends and propositions for future development. Research paper [6] highlights that domestic research on the aerial spraying application of plant protection UAVs primarily focuses on the impact of aerial spraying operation parameters on the distribution of droplet deposition. However, it tends to overlook the evaluation and testing of the effective spraying width of aerial spraying by plant protection UAVs. Even though the exact method, equipment, and setting are crucial, the time of different interventions is also important. From irrigation systems we can learn that the dose, and the way of application can bring savings in financials, and in water usage too [7]. Reducing, or better called optimizing deposit volumes can be achieved by using finer nozzles, changing travel speeds, or using air assistance. Air assistance can increase the possibility of aiming vertical targets [8]. In [9], a study was conducted to ascertain the effects of different parameters on spraying. It was observed that the operating speed of the sprayer had a significant impact on spray droplets deposition and distribution, being notably greater at lower operating speeds. In air-assisted sprayers, an increase in blower speed significantly enhanced drift force and expanded the tree canopy area covered in spraying. In [10], an integrated computational fluid dynamics (CFD) model was developed. This model predicts the displacement of PPP spray droplets discharged from an air-assisted sprayer, their depositions onto tree canopies, and off-target deposition and airborne drift in an apple orchard. In order to maximize target deposition, the outcomes made it evident how useful CFD models are for examining various sprayer configurations. As a result of the research presented in [11], CFD may be utilized as a tool for numerical prototyping, which cuts down on the number of tests. Also, the model's coupling with the droplet deposition and canopy airflow models already in use help the design and operation of sprayers with a lower risk of environmental contamination.

Environmental diversification also affects the quality of spraying. Therefore, in the paper [12] the authors anticipated the need for a smart spray analytical system that helped the calibration of the air-assisted sprayer continuously. Several materials can be used in the droplet tracking workflow, like water-soluble food dye. Thanks to the approach from [13], it's possible to boost the amount of total deposition on the canopy from 48.4% to 65.6% of the applied dose, without significantly raising the amount of spray that is lost to the ground. Researchers in [14] were engaged in experimental studies on the design, development, and testing of precision spraying technologies for crops and orchards. Numerous new alternative methods were published. For example, research in [17] shows that UAVs can serve as a potential machine that can work as an alternative for spraying applications. With water-sensitive paper, the nature of airflow is discussed. Coverage was measured in several levels of the canopy, in the aim to have a better understanding of the behavior of the deposit. Even though the unit can be used as an air-assisted sprayer, the volume of mixed chemicals is reduced. The droplet deposit is lower than by using conventional methods, but it doesn’t necessarily mean that the volume of active ingredient is also reduced. According to the results of research presented in [18] the way of measurement can be improved by other methods. AI-based algorithms and machine learning can provide precise, and fast decision making in real time droplet management. The review presented in [19] reveals that drones can redefine agriculture in a way that drives this industry on a new path. Implementation of modern technologies is able, for example, to perform electromechanical flow control and cutting-edge nozzles, and transformative AI.

3. MATERIALS AND METHODS

3.1. PATH PLANNING FOR OPTIMAL AREA COVERAGE

Ardupilot Mission Planner is a comprehensive software application used for configuring and controlling unmanned vehicles that run on the Ardupilot open-source autopilot firmware. Ardupilot is one of the most advanced, full-featured, and reliable open-source autopilot software available, supporting a wide range of UAVs [20, 21]. It is necessary to provide the key GPS coordinates of the area for the software to calculate the overflight path of the given surface as shown in Fig. 2.

Fig. 2. Mission planner environment

A mission planner is capable of planning complex missions with multiple waypoints and conditional commands and offers real-time data streaming from the vehicle, enabling live monitoring of various metrics such as altitude, speed, battery status, and GPS data [22].

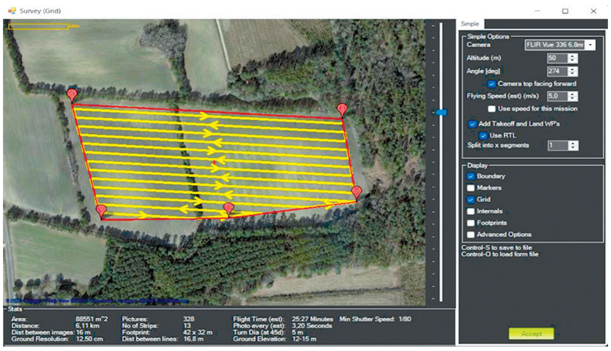


Fig. 3. Planning a mission with waypoints and events

Mission Planner is particularly popular among hobbyists, researchers, and professionals in the field of unmanned systems, as it provides a user-friendly interface and a rich set of features for effectively managing and controlling unmanned missions. It runs on Windows and is integrated to many Ardupilot-based UAV operations. Defining the drone's flight path is solved by the Ardupilot software package, which calculates the coordinates that the aircraft will follow in order to optimally cover the defined area as shown in Fig. 3. After planning the optimal path of the drone over the defined area, the flight plan is executed, and the area is dusted.

3.2. PROPOSED METHODOLOGY FOR THE SPRAYING QUALITY EVALUATION

To be able to determine the quality of dusting, water-sensitive paper indicators are placed in appropriate places in the investigated area. After the spraying the paper slips are collected and digitized.

Algorithm 1 outlines the steps for measuring droplet deposition from an image containing sprayed droplets. It involves preprocessing the image, identifying droplet spots, extracting relevant features, and visualizing the results for analysis and interpretation. The search for pixels consisted of the following steps:

1. Color Space Transformation;
2. Thresholding;
3. Morphological Operations;
4. Region Analysis;
5. Statistical Analysis;
6. Visualization.

To implement these steps, a MATLAB script and applied MATLAB's built-in image processing functions were used.

The method presented in this article analyzes the dusting quality, i.e. the size of the droplets. The pseudocode serves as a blueprint for implementing the algorithm in software. It outlines the steps and logic required to analyze the quality of dusting, providing guidance for programmers tasked with writing the actual code.

Algorithm 1 The droplet deposition measurement

```
1   % Looking for blue spots from image
    img = imread('Original source image.jpg');

2   % Color sharpening (Identification of blue spots)
    blueMask =(img(:,:,1) >0 & img(:,:,1) < 80) & ...
        (img(:,:,2) > 0 & img(:,:,2) < 80) & ...
        (img(:,:,3) > 0 & img(:,:,3) < 200);

3   % Morphological Operations (Noise Reduction)
    % Remove spots smaller than 50 pixels
    blueMaskCleaned = bwareaopen(blueMask, 5);

4   % Labeling (Spot Labeling)
    labeledBlueObjects = bwlabel(blueMask);

5   % Feature Extraction (Definition of Properties)
    stats = regionprops(labeledBlueObjects, 'Area',
    'Centroid', 'Perimeter');

6   % Histogram (Histogram of spots by area)
    areas = [stats.Area];
    histogram(areas);

7   % Display spots on the image
    imshow(img);
    hold on;
    for i = 1:numel(stats)
        plot(stats(i).Centroid(1), stats(i).Centroid(2), 'r+');

8   % Display of spot centers
    plot(stats(i).Centroid(1), stats(i).Centroid(2), 'r*');
    end
    hold off;

9   % Show results
    figure;
    imshow(blueMask);
```

The algorithm facilitates the digitization of data collected from the paper slips. This process is essential for transforming raw observational data into a format that can be analyzed and interpreted by computational methods, enabling quantitative assessment of dusting quality. By analyzing the droplet distribution on the water-sensitive or substance-sensitive papers collected from certain areas, the algorithm helps evaluate the effectiveness of the spraying process. This assessment is vital for ensuring optimal coverage and efficacy in agricultural spraying operations.

3.3. MEASUREMENT SYSTEM

The device used to assist us in completing the task was a Cognex In-Sight 7000 industrial camera. It is a high-performance and reliable tool that greatly facilitates and accelerates the counting process of droplets. The specific camera used has a resolution of 640 x 480 / 800 x 600 pixels. It provides high-speed and fast processing capabilities, enabling quick image processing and data analysis. It features built-in image processing capabilities, such as contour detection, shape recognition, and other functionalities. It allows communication via Ethernet, RS-232, and USB interfaces. The camera is housed in a robust aluminum casing with IP67 protection. Fig. 4 shows the physical dimensions of the Cognex In-Sight industrial camera.

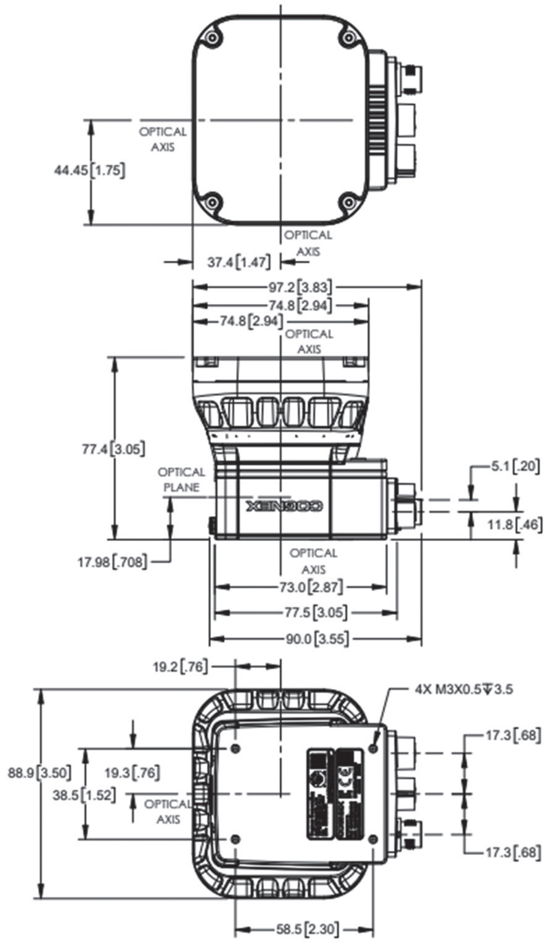
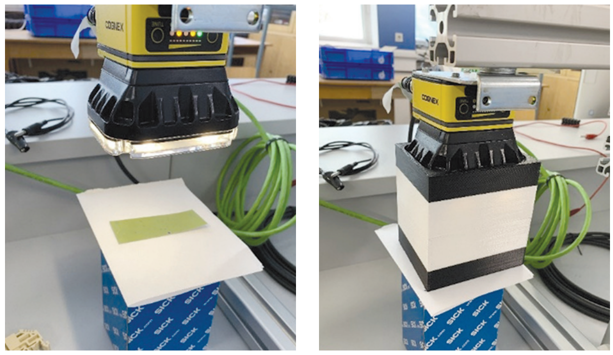


Fig. 4. The physical dimensions of the Cognex In-Sight industrial camera

The camera communicates with multiple software, and a program called In-Sight Explorer. For this task, the settings and filters to easily locate and count the droplets on the water-sensitive papers were adjusted. The camera has its own built-in LED lights, which illuminate the paper placed in the focal point due to their high brightness. External lighting for the task was not used, but there were external ambient lights present [23]. These external lights disrupted the measurement process as the camera could not accurately detect the positions of the droplets. The multiple light sources caused the image to become blurry. The camera uses an M12 lens type, which is equipped with a chain of circularly arranged LED lights. There are a total of 8 built-in LEDs. These lights can be toggled on and off to aid in focusing as depicted in Fig 5.



(a) (b)

Fig. 5. (**a**) Digitalization without constant light chamber and (**b**) Digitalization with constant light chamber

Since the LED light is directional, it caused significant reflection due to the paper's surface properties, resulting in focusing issues. To address this, a solution was implemented where a diffusing film directly after the LEDs was placed. This achieved light diffusion, preventing the reflection from the paper surface. Table 1 shows the droplet classification system ASAE standard S-572.

Table 1. Droplet classification system ASAE standard S-572

Nozzle category	Symbol	Colour code	VMD
Very fine	VF	Red	<150
Fine	F	Orange	150-250
Medium	M	Yellow	250-350
Coarse	C	Blue	350-450
Very coarse	VC	Green	450-550
Extremely coarse	XC	White	>550

The methodology takes into account factors such as spray rate, UAV speed, climatic conditions, and wind speed, ensuring a holistic approach to spray quality evaluation as shown in Table 2.

By providing insights into the effectiveness and characteristics of plant spraying techniques, this study contributes to the advancement of precision agriculture practices, ultimately leading to improved crop health and productivity. By considering factors such as spray rate, UAV speed, climatic conditions, and wind speed, the methodology offers a comprehensive approach to spray quality evaluation, enabling farmers to make informed decisions and optimize spraying operations.

Table 2. Agricultural spraying operation factors

Parameter	Values
Spray Rate	12.5 liters/hectare
UAV Speed	3 meters/second
Climatic Conditions	Temperature: 25°C Humidity: 60% Atmospheric Stability: Stable
Wind Speed	5 meters/second
Droplet Size	Reference ASABE S572

4. RESULTS

It has been shown in studies that among various factors, droplet size is the most significant in causing spray drift. The smaller the droplet, the longer it remains airborne and the more susceptible it becomes to drifting with the wind.

Table 3. Effects of droplet sizes on drift potential

Droplet diameter /µm	Suspension time required for droplets to drop by 3 m/s
5	3960
20	252
100	10
240	6
400	2
1000	1

Table 3 contains the effects of droplet sizes on drift potential. Meteorological parameters are essential factors that cannot be overlooked in the examination of droplet deposition and drift. During the process of droplet deposition from the nozzle to the ground, droplets are influenced by temperature and relative humidity, and evaporation results in the reduction of droplet size, making them more prone to drifting extensively in the natural wind [23, 24]. Therefore, the primary meteorological parameters that affect droplet deposition and drift include natural wind, temperature, humidity, and atmospheric stability.

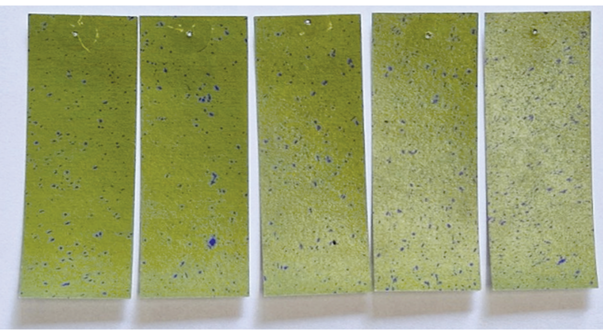


Fig. 6. Water-sensitive papers after the UAV-assisted particle spraying process

For the analysis, water-sensitive papers were placed under the leaves of the plants to ensure the accuracy of spraying i.e. the droplet deposition measurement as depicted in fig. 6. When the spray comes into contact with these papers, they undergo color changes. The droplets, varying in size depending on the amount of liquid, help in determining the proper air-to-water ratio during the spraying process. Different results were provided by the collected papers due to modifications in the spraying process. The task involved gathering these papers and studying the droplets formed on them. To expedite the counting process, industrial cameras are being used.

IMAGE PROCESSING OF THE SAMPLES AND DROPLET SEGMENTATION

Image processing on the computer could begin after scanning the samples. Each sample was individually saved and processed separately. In this work, the processing of only two samples is presented, but the same algorithm has been applied for all samples as well.

COLOR SPACE TRANSFORMATION

The MATLAB code represents a classic approach in image processing to segment and analyze specific regions or features of interest, commonly referred to as "blobs" or "regions". In this instance, the regions of interest are potentially blue-colored in the image. The image in MATLAB will be in a matrix form where each pixel is represented by its RGB (Red, Green, Blue) values. Digital images are typically represented in the RGB color space, where each pixel's color information is encapsulated by three intensity values corresponding to the red, green, and blue channels. However, the RGB representation is not always ideal for segmentation tasks, primarily due to the tight coupling between color and intensity. Consequently, many segmentation tasks leverage the HSV (Hue, Saturation, Value) color space. In HSV, colors are described based on their hue (type of color), saturation (vibrancy), and value (brightness). This transformation provides a more intuitive paradigm for many image analysis tasks, as hue decouples color information from luminance, often simplifying the segmentation process. Fig. 7 presents the original RGB picture, the HSV color space picture and every component of the HSV picture.

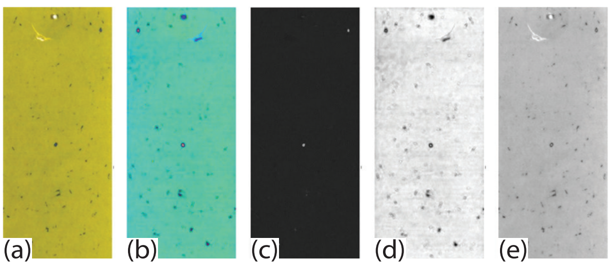


Fig. 7. Water-sensitive paper in the image processing: (**a**) Original RGB picture, (**b**) HSV color space picture represented in MATLAB, (**c**) Hue component, (**d**) Saturation component, (**e**) Value component

From the images, it is clear that useful information can only be obtained from the Saturation and Value components. This is where the droplets can be best distinguished. In the remainder of the paper, the Saturation component was used.

THRESHOLDING

The histogram of the Saturation component shows which values the pixels take and what distribution they follow (see Fig. 8). This information will be crucial for the subsequent segmentation of the image.

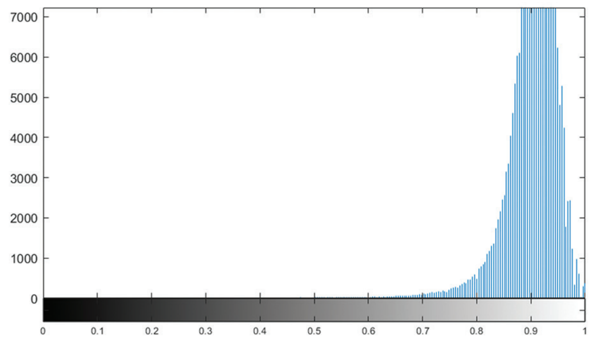


Fig. 8. Histogram of the Saturation component

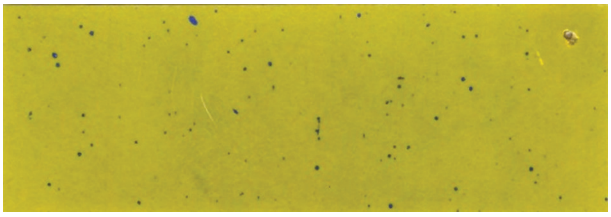
An image thresholding technique was used to segment the blue spots on the water-sensitive papers. Specifically, a color-based thresholding method was applied to isolate the blue regions from the background. This method ensures accurate identification and measurement of spray droplets. A widely utilized technique in image segmentation is thresholding. It involves categorizing pixel values based on specific thresholds and creating a binary mask where pixels within the desired range are highlighted. In this instance, the Saturation channel of the HSV image is subjected to thresholding to identify potential dark blue droplets. The rationale behind targeting the Value channel is based on the understanding that blue regions might possess a specific brightness range, which can be isolated via thresholding. By setting lower and upper bounds on this channel, a mask that potentially contains blue spots is obtained. The best result can be obtained with the usage of lower bounds of 0.3 and the upper bound is set to 0.6.

MORPHOLOGICAL OPERATIONS AND REGION ANALYSIS

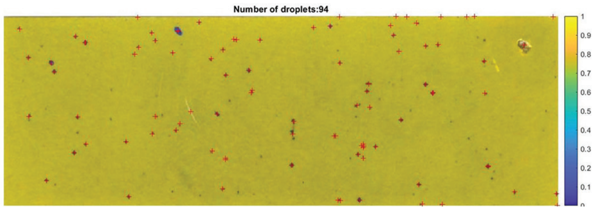
Following thresholding, images often contain noise or small unwanted artifacts. Morphological operations offer tools for refining segmented regions, enhancing the accuracy of the segmentation. Two such operations are:

- Area opening: This operation removes small connected components or blobs based on a specified pixel threshold, ensuring the elimination of noise and tiny undesired regions;
- Hole filling: Sometimes, segmented regions may have small gaps or holes. Hole filling ensures that these regions are filled, providing a more coherent segmented region.

Once the regions of interest are segmented, one may desire to extract properties from these regions for further analysis. The region-props function in MATLAB facilitates the extraction of numerous properties from labeled regions. In this context, the area, centroid, and filled area of the detected spots are extracted. These parameters offer insights into the size, distribution, and morphology of the detected blue spots. Using the aforementioned functions, some results can be seen in Figs. 9 and 10.

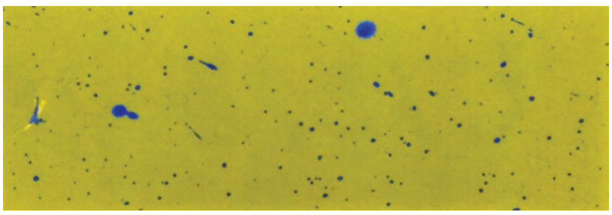


(a)

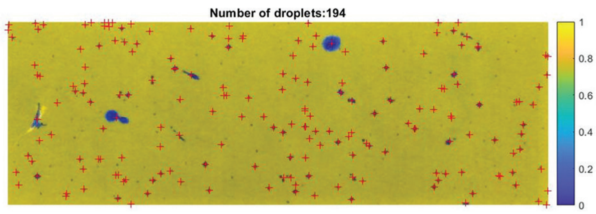


(b)

Fig. 9. (**a**) Original sample 1 and (**b**) processed sample 1



(a)



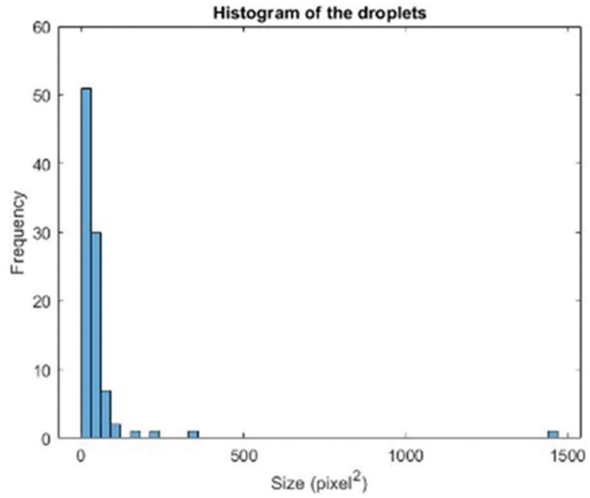
(b)

Fig. 10. (**a**) Original sample 2 and (**b**) processed sample 2

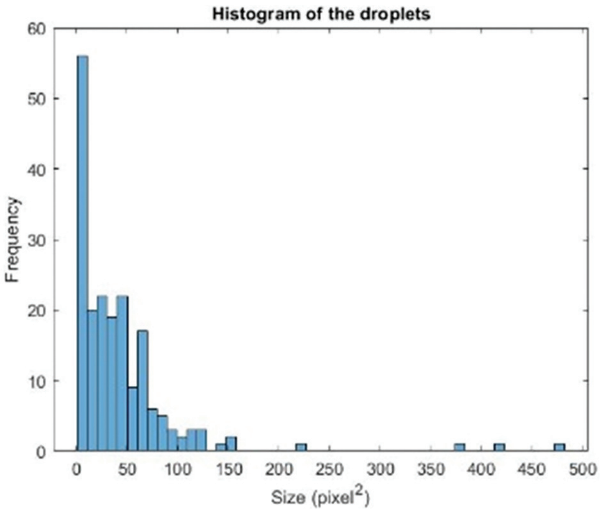
STATISTICAL ANALYSIS AND VISUALIZATION

Subsequent to the extraction of properties, statistical analyses, such as plotting histograms, can be employed to understand the data's distribution. Histograms represent data distribution by organizing a series of data points into user-defined ranges.

In this context, the area of the detected blue spots is visualized using a histogram, providing insights into the size distribution of these spots. Such visual statistical tools are pivotal in understanding the underlying patterns and characteristics of segmented features. Visual validation is an integral aspect of image processing, allowing researchers to confirm the efficacy of their methodologies as can be seen in Fig. 11.



(a)



(b)

Fig. 11. (**a**) Histogram of the sample 1 and (**b**) sample 2

In the code, the original image is overlaid with markers indicating the centroids of the detected blue spots, providing a visual affirmation of the segmented regions. The accuracy of image processing can be improved by enhancing the scanning quality and by fine-tuning the threshold parameters. The quality of the water-resistant paper also greatly affects the quality of image processing. If the system has not been calibrated properly for the lighting conditions or the specific camera being used, it can result in inaccuracies in the HSV color space conversion, subsequently affecting the segmentation process. Factors like uneven lighting, shadows, or reflections can affect the appearance of objects in the image, potentially leading to inaccuracies in detection.

5. CONCLUSION

In conclusion, the presented methodology exemplifies a structured approach to image segmentation and analysis. By leveraging the unique properties of the HSV color space, combined with thresholding, morphological refinements, and statistical analyses, one can accurately segment and interpret specific features in an image. Such techniques, rooted in the fundamental principles of image processing, offer a scientific approach to extract patterns and features from complex image data. As the ecological environment continues to deteriorate and people's expectations for modern life quality increase, increasing attention is being paid to the issues of PPP pollution and residues. Consequently, the trend in PPP usage is inevitably moving towards achieving a higher utilization rate of PPP and minimizing environmental pollution. An analysis of the spray drift mechanism and a review of prior studies have revealed that factors such as droplet size, meteorological parameters, nozzles, operating parameters, and the physicochemical properties of liquid medicine all influence the droplet deposition and drift in aerial spraying. Therefore, employing an effective combination of low- or ultra-low-volume spraying operation modes in aerial spraying is an important strategy to attain this goal. By optimizing spray quality and distribution, our methodology helps reduce PPP use, lower environmental pollution, and promote sustainable farming practices.

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