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Design and application of a system for droplet-size measurement in the field based on micro-distance imaging technology

Chengda Sun [a, b], Weimin Ding [a, *], Liangfu Zhou [a], Wei Qiu [a], Jiabing Gu [a]

[a] College of Engineering, Nanjing Agricultural University, Nanjing 210031, Jiangsu Province, China
[b] Co-Innovation Center of the Intelligent Management and Equipment for Orchard on the Hilly Land in South China, Nanchang 330013, China

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A B S T R A C T

A measurement system was developed using micro-distance imaging technology to measure droplet sizes in the field. Legible droplet images were acquired with a single-lens reflex camera, a micro-distance lens and illumination source in the proper parameters. The droplets were extracted effectively based on the background subtraction, region-growing repair, shape-factor screening and concave points matching methods. The droplet characterizations, including projective area, diameter and volume were calculated using MATLAB image processing technology. The system displayed droplet sizes and distribution regulation in graphs that were convenient for obtaining experimental regulation. Indoor comparison experiments between the developed system and oil disk method was conducted, and the average relative errors were 6.03%, 5.50% and 6.25% for $D_{V\ 0.1}$, $D_{V\ 0.5}$, $D_{V\ 0.9}$, respectively. Field comparison experiments revealed that the relative error was 5.61% between the developed system and the oil disk method and 6.88% between the developed system and the laser instrument method. Application experiments in the field were conducted and the result revealed that fine droplets had better penetration than coarse droplets in the tree canopy. The system was simple in structure, had a lower cost compared with some instruments and reduced experimental time compared with the image processing methods that use oil disks. It has a good prospect for use.

1. Introduction

Droplet size has an important influence on pesticide deposition and drift (Miller and Ellis, 2000; Nuttery et al., 2009), and the accurate measurement of droplet size is of substantial significance for improving the spray effect.

The primary methods used to measure droplet size are the laser instrument analysis method (Dorr et al., 2013; Nuyttens et al., 2007; Vallet and Tinet, 2013) and the particle/droplet image analysis (PDIA) (Kashdan et al., 2007; Lad et al., 2011). The laser instruments have good precision whereas they place a high requirement on the measurement environment.

The PDIA method is used to measure droplet characterization in a spray plane, and it can reflect droplet characterization comprehensively (Wang, 2015). The PDIA method is typically used in direct and indirect ways. For the direct way, the image of the droplet is directly obtained using a camera, and the droplet sizes are calculated based on the image information. Many of these direct approaches are used in the laboratory because light conditions in an outdoor environment are complex and variable. For the indirect way, droplets are collected using paper cards. Then, the droplet-mark sizes on the card are calculated using the image processing method. Finally, the actual droplet size is calculated according to the relationship between the actual droplet size and the mark size on the paper card. Although the indirect approach has lower requirements on the measurement environment, several factors require consideration: the transformation relationship between the actual droplet size and the mark size on the paper card is influenced by the physical properties of the spray liquid and paper card's absorbent properties (Franz, 1993); the entire process is divided into several phases, decreasing measurement precision and increasing experimental time.

In this article, a system using micro-distance imaging technology was developed to measure droplet size.The contents are as follows.

* Corresponding author.
E-mail addresses: njauscd@163.com (C. Sun), wmding3@163.com, wmding@njau.edu.cn (W. Ding).

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(1) By using MATLAB software, the droplet region in the image was extracted, the droplet sizes were calculated and the measurement results were displayed with graphs on the PC interface.
(2) Comparison experiments among the developed system, the oil disk method and the laser instrument method were conducted to validate its precision.
(3) The influence of droplet number density on measurement precision was investigated.
(4) Application experiments in the field were performed to verify the applicability of the developed system; In addition, the tree canopy penetration regulation of droplets with different sizes was investigated.

2. Material and methods

2.1. Technical framework

The measurement system consisted of a droplet image-acquisition module, an image-processing module, a data-calculation module and a data save-and-display module. Fig. 1 shows the measurement process.

2.2. Hardware platform

The developed system consisted of the device shell, a single-lens reflex camera, a micro-distance lens, the illumination source, gratings, a droplet-collection slot, a device support, a black cloth to absorb light and a PC (Fig. 2).

The shells for the device were 35 cm × 10 cm × 5 cm in size (part 5 and part 7 in Fig. 2), and they were made of steel with plastic-sprayed surface and the thickness was 1 mm. The illumination source was LED light (100 W, 24 V). The black cloth was thickened and flocked to obtain a good effect of light absorption. The gratings were made of metal sheets with rectangular hole of 6 mm × 100 mm.

2.2.1. Design of droplet-collection device and device support

Shell 5 was moved along four metal slide bars fixed on the four corners of shell 7 to change the width of the droplet collecting slot, which controlled amount of droplets entering the slot. If the width was too wide, too many droplets would enter, causing an increase in the number of overlapping droplets. If the width was too narrow, the number of droplets would decrease to affect measurement precision. When the droplet number density in the spray was not high, the droplet collecting slot was usually adjusted to the width equal to the depth of field (it was 6 mm by measurement). If the droplet number density in spray was high, the droplet number entering the slot should be less than N. N was determined by Eq. (1). For a measured droplet group, the slot width was slightly less than L and L was determined by Eq. (2). The droplet-collection plane was normal to the central axis of the camera lens so that it was within the range of the depth of field.

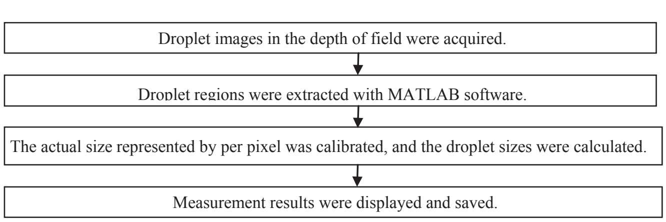
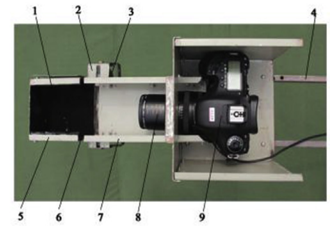


Fig. 1. Technical framework of the developed system.



1. Black cloth for light absorption; 2. Grating; 3. Illumination source; 4. Sliders; 5. Shell; 6. Droplet collecting slot; 7. Shell; 8. Micro-distance lens; 9. Camera

Fig. 2. Structural schematic of the developed system.

$$N = \rho_{max} \cdot d_{max} \cdot S \quad (1)$$

$$L = \frac{N}{\rho \cdot S} \quad (2)$$

where N is the droplet number entering the slot, which is obtained through the image, d_{max} is the maximum diameter for a certain type of droplet group, i.e., the allowed minimum width of the droplet collecting slot, ρ_{max} is the droplet number density that should be controlled based on measurement precision (more details refer to section 3.3), S is the imaging area (5.00 cm × 3.33 cm), L is the proper slot width for a measured droplet group, and its number density is ρ.

Fig. 3 shows the structure of the device support. The device support was moved along two 3 m horizontal guide rails. The height of the cross beam was adjusted steplessly using a halyard-and-capstan system within a range of 1.1–2.2 m above the ground. The measurement device was installed on the slide bars, which was moved forward and backward on the cross beam within a range of 0.65–2.0 m from the straight beams. This design enabled the measurement device to be quickly positioned (see Fig. 3).

2.2.2. Illumination source and background arrangement

Light intensity and homogeneity were the keys to determining image quality. A weak light intensity affected droplet imaging quality, and light inhomogeneity caused incomplete droplets to appear in the image. The theory of geometric optics can be applied to analyse the phenomenon of light scattered by the droplets if the size of the droplets (approximately 100 μm) is much larger than a light wave (400–760 nm). Based on the theory of light refraction and reflection, three different types of light require consideration

1. Designed system; 2 and 6. Cross beam;
3and 5. Slide bars; 4. Halyard; 7. Straight beam;
8. Guide rails; 9. Capstan

Fig. 3. Device support structural diagram.