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DEVELOPMENT OF AN IMAGING SYSTEM FOR SINGLE DROPLET CHARACTERIZATION USING A DROPLET GENERATOR

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SUMMARY

The spray droplets generated by agricultural nozzles play an important role in the application accuracy and efficiency of plant protection products. The limitations of the non-imaging techniques and the recent improvements in digital image acquisition and processing increased the interest in using high speed imaging techniques in pesticide spray characterisation.

The goal of this study was to develop an imaging technique to evaluate the characteristics of a single spray droplet using a piezoelectric single droplet generator and a high speed imaging technique. Tests were done with different camera settings, lenses, diffusers and light sources.

The experiments have shown the necessity for having a good image acquisition and processing system. Image analysis results contributed in selecting the optimal set-up for measuring droplet size and velocity which consisted of a high speed camera with a 6 µs exposure time, a microscope lens at a working distance of 43 cm resulting in a field of view of 1.0 cm x 0.8 cm and a Xenon light source without diffuser used as a backlight.

For measuring macro-spray characteristics as the droplet trajectory, the spray angle and the spray shape, a Macro Video Zoom lens at a working distance of 14.3 cm with a bigger field of view of 7.5 cm x 9.5 cm in combination with a halogen spotlight with a diffuser and the high speed camera can be used.

Key words: Droplet generator, droplet characteristics, high speed imaging techniques

INTRODUCTION

The spray droplets generated by agricultural nozzles play an important role in the application accuracy and efficiency of plant protection products. Nevertheless, the mechanisms of droplets leaving a spray nozzle and impacting the leaves are very complex, difficult to quantify or model and the existing techniques are not able to fully characterize the spray application process, therefore a need for accurate quantification technique exists. The limitations of the non-imaging techniques and the recent improvements in digital image acquisition and processing increased the interest in using high speed imaging techniques in pesticide spray characterization (Hijazi *et al*., 2012).

The process of desirable droplet size ejection and tracking is not a simple process and consequently, choosing a good image acquisition system is a real challenge.

The goal of this study was to build an image acquisition and image analysis system for tracking and characterizing droplets generated with a single droplet generator by testing different

high speed camera settings, illuminations, diffusers and lenses. The evaluation of the tested image acquisition systems is done using image analysis and is based on
1) the image quality parameters,
2) the light stability and exposure time and
3) the droplet measuring accuracy.

In future, the developed image acquisition set-up will be used to characterize a single spray nozzle and real sprayer application.

MATERIALS AND METHODS

Imaging system

A high power light source as a background illumination against the droplet generator combined with a high-speed camera and a frame capture device is the method used for imaging the droplets (Figure 1). Different lenses and illumination systems were evaluated (Table 1).

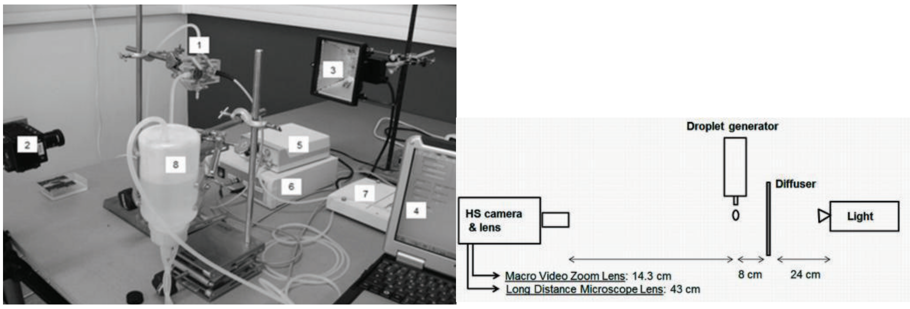

Figure 1. Picture (left) and schematic (right) of the imaging system set-up with 1-Droplet generator with piezoelectric element, 2-High-speed camera and lens, 3-Light source, 4-Computer with frame software, 5-Pressure supplier, 6- Signal amplifier, 7- Pulse generator, 8- Liquid tank.

High speed camera and image acquisition software

The used N3 High-speed camera (IDT, Lommel, Belgium) has a 1” CMOS sensor type with a 12 µm pixel size and a maximum resolution of 1280 x 1024 pixels (1.3 megapixels). The imaging frequency of the high speed camera was set to 1000 Hz (1000 fps) with a +3 dB sensor gain (Massinon *et al*., 2012). All tests were done at 3 exposure times: 5, 10 and 15 µs. Additional tests were done with the Xenon light with the K2/SC Long-Distance Microscope System Lens without diffuser at exposure times of 6, 7, 8 and 9 µs.
In order to image a droplet, the droplet ejection was triggered with the camera.
The software package Motion Studio (IDT, Lommel, Belgium, version: 2.09, 2011) was used as a frame capture device for choosing the settings of the HS camera like frame rate, record mode, sensor gain, image resolution and exposure mode. For each of the 54 lens/glass/light/exposure time combinations (Table 1) droplet ejection videos with 100 images were taken. Once a droplet could be detected visually in these videos, 10 consecutive images with a droplet were selected for image analysis. Similarly, from these videos, 10 consecutive images were also selected without a droplet for further image analysis.

Lenses

Two types of lenses were evaluated. A Macro Video Zoom Lens (Optem, NY, USA, Focal length: 18-108 mm, F/2.5-Closed, 2/3'' format,) with close-up lens was used (Kim *et al*., 2011) at a working distance of 14.3 cm resulting in a field of view (FOV) of 7.5 cm x 9.5 cm. For the purpose of achieving a small FOV, we also used a K2/SC Long-Distance Microscope Lens (Infinity, USA), (Riefler *et al*, 2008) with a CF1 Objective directly attached to its front at a working distance of 43 cm resulting in a FOV of 1.0 cm x 0.8 cm (Infinity Photo-Optical Company, 2009).

Illumination and diffusers

Knowing that the droplet velocity is high, the exposure time should be in the time range of few µs. Such a short exposure time requires high illumination intensities (Riefler *et al*., 2008). Moreover the light should be easy to maintain a stable illumination which requires a highly-regulated voltage supply.

Therefore, three types of light sources (Power LEDs, Halogen spotlight, Xenon light) were tested with and without two types of diffusers (Table 1).

Firstly, a seven star power LED 40 mm Round Assembly (Philips, Lumileds, USA, 5650 K, 14W) with Polymer 264 lens and DC power supply delivering 1645 lm at 700 mA (Sunrise, Hamburg, Germany, 10x3LSD). Furthermore, we used a Halogen spotlight (Philips, Ecohalo 350 W) (Ulmke *et al*., 2001) with a maximum power of 500 W and a working temperature of 3200 K. This type of lighting is the least expensive, but care must be taken not to overheat any object in the record scene.

Finally, for the purpose of achieving a clear image even at a very short exposure time, a Xenon short arc lamp (WOLF 5132, Knittlingen, Germany, 300 W) was also included, fed to the head by a flexible light conductor (Kim *et al*., 2011). It is easy to handle and capable of providing instant high-power white light and a high-intensity continuous spectrum with low heat build-up.

A simple and effective way of reducing light inhomogeneity involves the use of a diffuser placed between the light and the lens (Lad *et al*., 2011) (Figure 1). Two types of ground glass diffusers (TECHSPEC, Edmund Optics, USA) were used: a 120-grit and a glass with a 220-grit sandblast, both with a thickness of 1.6 mm and a size of 250 mm x 250 mm.

Droplet generator

The droplet generator was made at the Université de Liège, Gembloux, Agro-Bio-Tech, Belgium) and is able to form uniform droplets in 2 modes: Droplet-On-Demand (DOD) and continuous mode (Rayleigh Breakup). In this study, droplets were generated in DOD mode using a glass nozzle with a supposed 150 µm orifice size.

An overview of the different experiments is shown in Table 1 corresponding with 2 lenses x 3 light sources x 3 diffusers x 3 exposure times = 54 combinations.

Table 1. Summary of the image analysis experiments

Lens	Light	Diffuser	Exposure time (µs)
Macro Video Zoom Lens	7 star power LED	120 grit	5, 10 and 15
		220 grit	
		none	
	Halogen spotlight	120 grit	5, 10 and 15
		220 grit	
		none	
	Xenon	120 grit	5, 10 and 15
		220 grit	
		none	
K2/SC Long-Distance Microscope system	7 star power LED	120 grit	5, 10 and 15
		220 grit	
		none	
	Halogen spotlight	120 grit	5, 10 and 15
		220 grit	
		none	
	Xenon	120 grit	5, 10 and 15
		220 grit	
		none*	

* additional tests at 6, 7, 8 and 9 µs exposure time

Image analysis

Image analysis combines techniques and measurements based on the gray level intensities of the image pixels on the histogram and were used here to determine the image characteristics from the different image acquisition systems (Table 1). Moreover, instead of using the image histogram directly for the image analysis, we decided to define and use statistical parameters of first order that were obtainable directly from the image histogram.

The first order statistics measure the likelihood of observing the image gray value in a region of interest (ROI) beneath the nozzle. For the Macro Video Zoom Lens, the ROI was located at 0.5 cm below the nozzle with the dimensions of 1.75 cm x 4.5 cm as illustrated in Figure 2. For the K2/SC Long- Distance Microscope Lens, the ROI was at 0.8 mm below the nozzle with dimensions of 0.25 cm x 0.80 cm (Figure 2). In both cases, the dimensions of the ROI were big enough to capture one and the same droplet in at least 10 consecutive images.

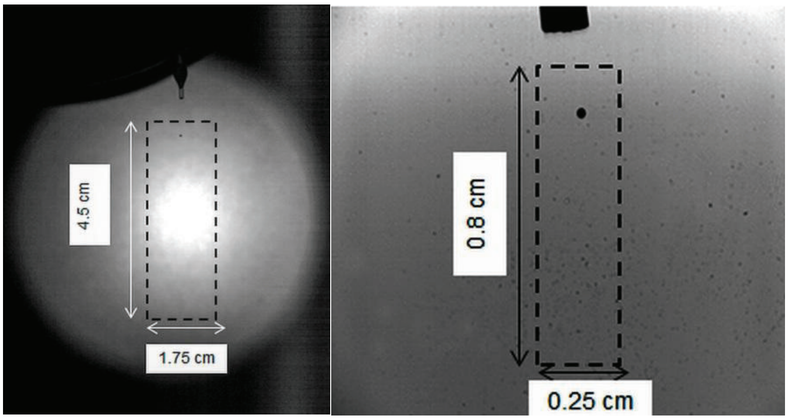

Figure 2. Region of interest (ROI) with the use of the Macro Video Zoom Lens, example of the Xenon light with 120 grit diffuser glass at 15 µs exposure time (left) and Region of interest (ROI) with the K2/SC Long-Distance Microscope Lens, example of the Xenon light, without diffuser at 5 µs exposure time (right).

The first order statistics is computed by using the probable density function $p(z_i)$ of occurrence of the intensity levels: by dividing the $\mathrm{h}(\mathrm{z_i})$ (the image histogram) with the total number of pixels in the ROI: $N_x N_y$ (N_x- width, N_y– height).

$$\mathbf{h}(\mathbf{z_i}) = \sum_{\mathbf{x=0}}^{\mathbf{N-1}} \sum_{\mathbf{y=0}}^{\mathbf{M-1}} \boldsymbol{\delta}(\mathbf{f}(\mathbf{x}, \mathbf{y}), \mathbf{z_i}) \qquad [1]$$

$$p(z_i) = \frac{h(z_i)}{N_x N_y} \qquad [2]$$

The first order statistics equations that were used for the tests are the Average gray level or Mean, the Average contrast and the Entropy (Gonzalez *et al.*, 2004; Haralic *et al.*, 1973). These values were calculated for all the pictures with as well as for all the pictures without a droplet (Table 2).

Table 2. First order statistic equations.

Parameter	Expression
Mean *(Average gray level)*	$f_1 = \mu = \sum_{z_i=0}^{L-1} z_i \, p(z_i)$
Standard Deviation (Average contrast)	$f_2 = \sigma = \sqrt{\sum_{z_i=0}^{L-1} (z_i - \mu) p(z_i)}$
Entropy	$f_3 = e = -\sum_{z_i=0}^{L-1} p(z_i) \, log_2 p(z_i)$

*$L = \mathbf{2}^{\boldsymbol{B}}$ *is the number of quantized gray levels, where B is the number of bits.*

The mean is a measure of the average gray level of an image or the brightness of the selected ROI. The average contrast value tells how much the gray level of pixels differs from the mean value to detect if there are any substantial light or dark spots in the image. The entropy is a measure of disorder within the image. A high entropy value in the ROI would indicate the presence of an object, whereas a 0 value corresponds with a constant image (Gonzalez *et al*., 2004).

For this specific purpose of measuring the image quality of a single droplet application, three additional parameters were defined and calculated from these first order statistics i.e.:

1. The Entropy ratio
    - The ratio of the entropy values from pictures with a droplet and without a droplet taken with the same image acquisition technique;
    - Should be maximized as we are aiming for a maximal entropy in pictures with a droplet and a minimal entropy in pictures without a droplet.
2. The Contrast ratio
    - The ratio of the average contrast values from pictures with a droplet and without a droplet taken with the same image acquisition technique;
    - Should be maximized as we are aiming for a maximal contrast value in pictures with a droplet and a minimal contrast value in pictures without a droplet.
3. The signal to noise ratio (SNR)
    - Ratio between the mean (signal) and the standard deviation (or average contrast) for pictures with a droplet;
    - Should be maximized as we are aiming for a big signal value and a small noise value on images with a droplet.

Light stability was assessed by comparing the image histograms of 10 consecutive pictures without a droplet.

Image analysis algorithm

The first order statistics from Table 2 were calculated using an image processing program developed in Matlab (MathWorks, Massachusetts, U.S.A.) consisting of different steps (Figure 3):

- Step 1: Select an image for analysing;
- Step 2: Define the ROI on the images for analysing as described above and illustrated in Figure 2;
- Step 3: Show the selected ROI and the corresponding histogram;
- Step 4: Function texture computes the first statistical measures of the chosen ROI:
  - Normalization of the ROI histogram;
  - Function moments computes the statistical central moments of the ROI;
  - Compute the three texture measures: mean, std. deviation, and entropy;
- Step 5: Display and save the statistics results.

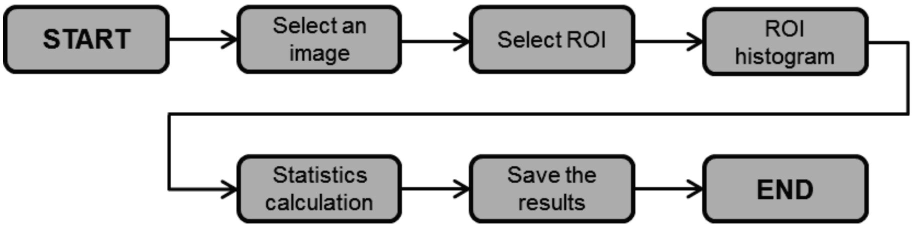

Figure 3. Flow chart for the image analysis.

RESULTS AND DISCUSSION

The different image acquisition systems were evaluated based on 3 criteria which are:

- *Image quality parameters*: Entropy ratio, Contrast ratio and Signal to noise ratio;
- *Light stability and exposure time*;
- *Droplet measuring accuracy*.

Image quality parameters

Entropy ratio, Contrast ratio and Signal to noise ratio for the different image acquisition systems are presented in Figure 4. Mind the different scale of the Y-axis.

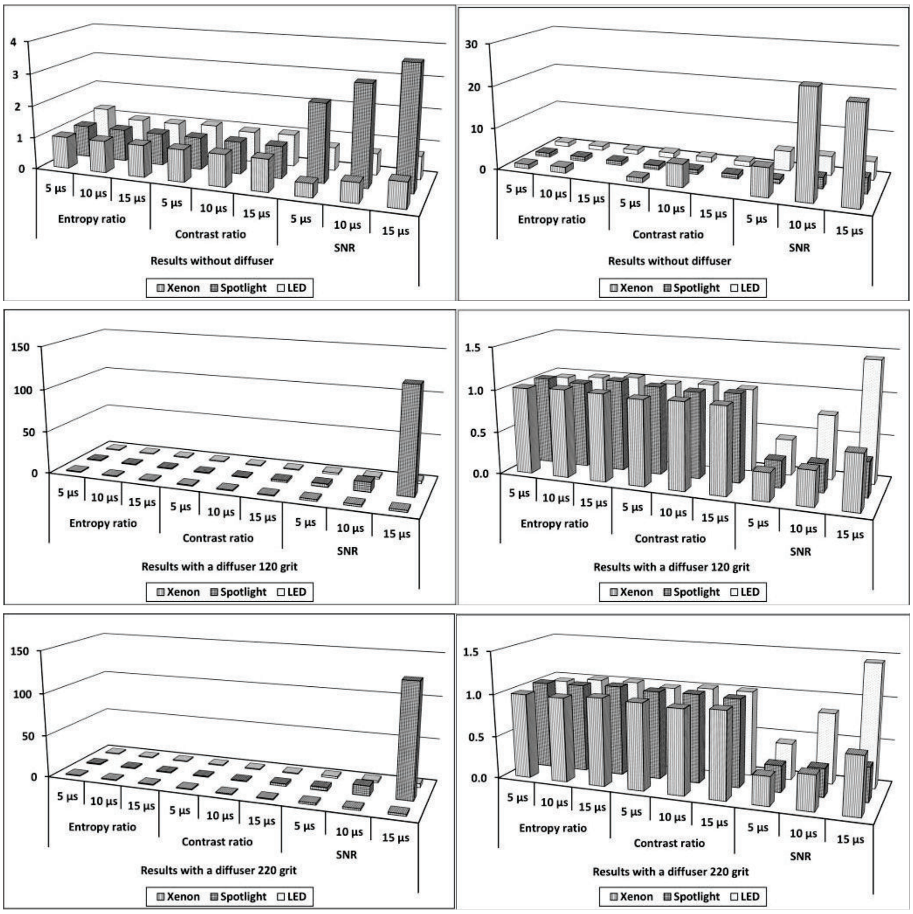

Figure 4. Image quality parameters (Entropy ratio, Contrast ratio and SNR) for the Macro Video Zoom Lens (left) and K2/SC Long-Distance Microscope Lens (right) for different exposure times and lighting systems (Table 1).

Some interesting observations can be made from Figure 4, for the Macro Video Zoom Lens as well as for the K2/SC Long-Distance Microscope Lens.

1. Macro Video Zoom Lens:
    1. Effect of diffuser: For the different lighting systems and exposure times, the use of a diffuser significantly improves the SNR. The difference between the 120 and 220 grit diffuser on SNR is limited although the best results are generally found for the 220 grit diffuser. The effect of a diffuser on entropy and contrast ratio is limited for the Xenon as well as for the LEDs lighting system. For the spotlight system, a diffuser improved the contrast ratio at the 15 µs exposure time.
    2. Effect of exposure time: For the spotlight with a diffuser, increasing the exposure time generally increased the SNR and the contrast ratio. Without a diffuser, increas-

   ing exposure time only increased SNR and not the contrast ratio. The effect on entropy ratio was limited. For the Xenon light, no effect of exposure time on entropy and contrast ratio was observed. SNR increased with an increase of exposure time. For the LEDs light, SNR increased with an increase of exposure time. No important effects of exposure time on entropy and contrast ratio were found except for the 5 µs exposure time without diffuser which resulted in a higher entropy ratio.
3. <u>Effect of light source</u>: The biggest values for the three parameters (Entropy, Contrast and SNR) are found with the spotlight at 15 µs exposure time and with a diffuser. From both diffusers, the 220 grit gave the best results (highest contrast ratio and SNR). At these settings, image quality parameters for the Xenon light and the LED light source are clearly lower.

2. K2/SC Long Distance Microscope Lens:

   1. <u>Effect of diffuser</u>: For the different light sources and exposure times, the use of a diffuser always gave worse results than without a diffuser. No significant differences were found between both types of diffusers.
   2. <u>Effect of exposure time</u>: The optimal exposure time was different for each of the light sources. For the LED, Xenon and spotlight (all without diffuser), best results for all parameters were found for an exposure time of, respectively, 5, 10 and 15 µs.
   3. <u>Effect of light source</u>: From the three light sources, the Xenon light (without diffuser at 10 µs exposure time) clearly gives the highest values for all the parameters tested. The LED light source without diffuser might be a valuable alternative because of the lower price and the relatively good results achieved in combination with a short exposure time of 5 µs.

In summary, using the results from Figure 4, four different lens/ light/ diffuser/time exposure combinations were selected for further analysis:

1. Macro Video Zoom Lens/Spotlight/120 grit diffuser/15 µs
2. Macro Video Zoom Lens/Spotlight/220 grit diffuser/15 µs
3. Microscopic Lens/Xenon light/no diffuser/10 µs
4. Microscopic Lens/LEDs/no diffuser/5 µs

Light stability and exposure time

A usable image acquisition setup for droplet characterization must be capable to deliver an adequate, even and stable scene illumination avoiding overexposed images. In order to achieve this, the four previously selected lens-light techniques are tested for their stability and overexposure rate.

Figure shows the image histograms of 10 consequent images without droplet for the 4 selected setups.

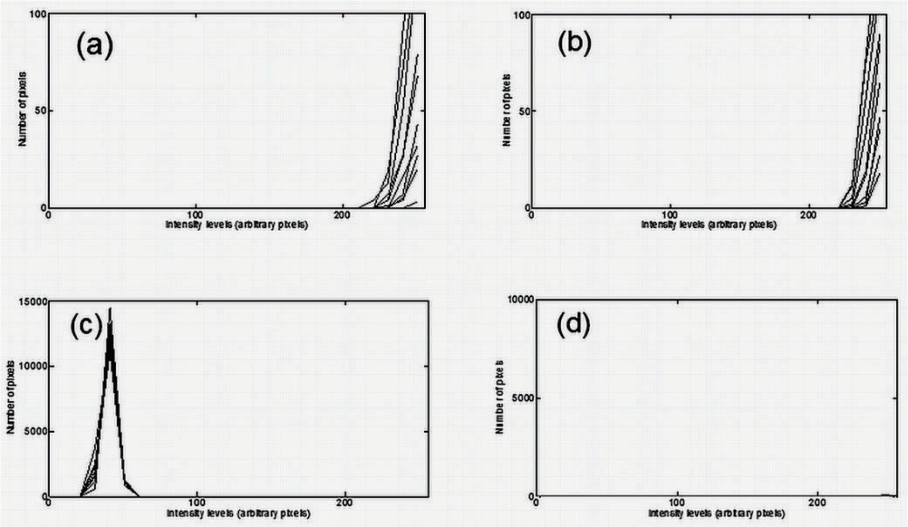

Figure 5. Histograms of 10 consecutive images: (a), (b) Macro Video Zoom Lens, Spotlight at 15 µs exp.time and 2 types of diffuser: 120, 220 grit, (c), (d) K2/SC Long-Distance Microscope Lens, Leds at 5 µs and Xenon at 10 µs without a diffuser.

The histograms of both Spotlight configurations (Figure 5a and b) are showing light instability and overexposure. This is due to using this light without AC/DC converter. Whereby, the light is driven by AC currents and show significant changes in intensity at recorded frames bigger than 120 Hz. Moreover, the light instability was also present for the shorter exposure times of 5 and 10 µs but reducing the exposure time, reduced the overexposure rate.

On the other hand, the use of the LEDs with the K2/SC Long-Distance Microscope Lens at 5 µs is giving a clear peak in the light distribution and stable histograms indicate a high stability but with relatively dark images (Figure 5c). The stability of the Xenon light cannot be assessed since at 10 µs exposure time the images are with complete overexposure (Figure 5d). Therefore, additional experiments were included with reduced exposure times of 6, 7, 8 and 9 µs using the Xenon light (Figure 6).

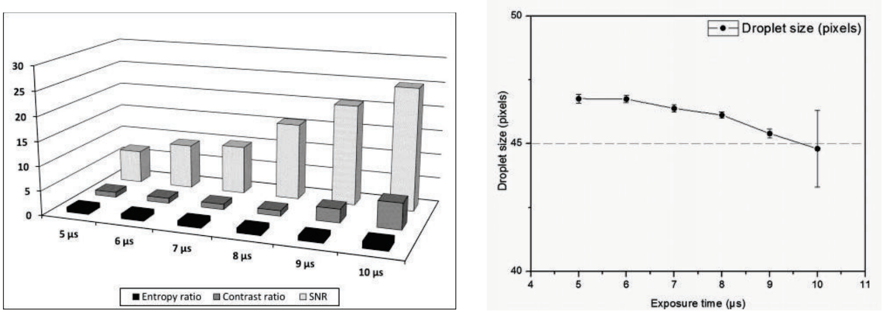

Figure 6. Image quality parameters for K2/SC Long-Distance Microscope Lens, Xenon light, without diffuser at 5, 6, 7, 8, 9 and 10 µs exposure time (left) and the effect of the exposure time on the droplet diameter measurement (right).

Looking at the results (Figure 6, left), it can be noticed that the increase of the exposure time significantly increases SNR and the contrast ratio. No correlation was found between the exposure time and the entropy ratio. At the same time, increasing the exposure time reduces the droplet size measurement (Figure 6, right), because of the effect of overexposure. To find the optimal exposure time, image histograms taken with the K2/SC Long-Distance Microscope lens and Xenon light at different exposure times are presented in Figure 7.

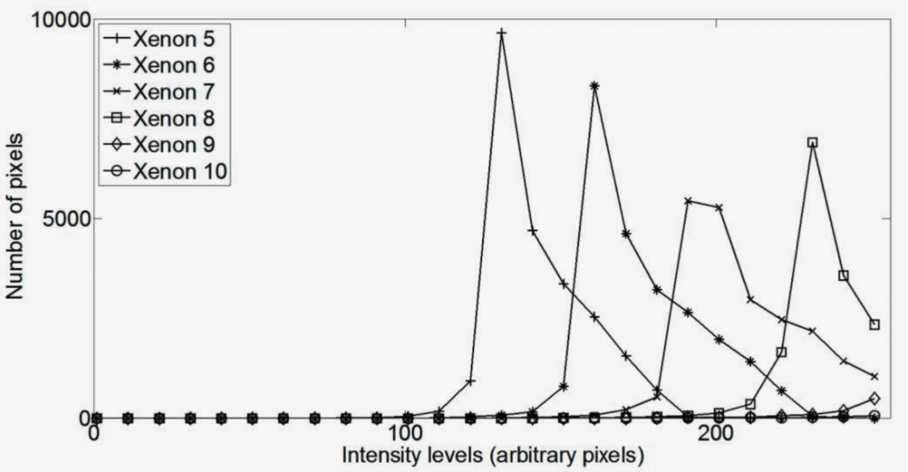

Figure 7. Image histograms using the K2/SC Long-Distance Microscope Lens and Xenon light without diffuser at 5 µs, 6 µs, 7 µs, 8 µs, 9 µs and 10 µs.

So, from the last Figure, 6 µs was chosen to be the optimal exposure time as it gives the brightest images without any overexposure as the complete histogram is in-between the 256 intensity levels (Figure 7). Moreover, this exposure time is short enough to capture the ejected droplet without any blurring despite the fast droplet motion.

Droplet measuring accuracy

In order to determine the correct droplet size and the measuring accuracy, the exact pixel size must be known for the different image acquisition set-ups. Therefore, a camera calibration was done which delivers a set of parameters that describe the camera's imaging process. An accurate calibration is crucial for applications which involve dimensional measurements. Next to the pixel size, camera calibration may show also on a possible image distortion.

The calculated pixel size for the Macro Video Zoom Lens found for the settings described on Figure 1 is 105.7 µm. This gives, a droplet size measuring accuracy of 105.7 µm which is too big knowing that droplet sizes in a pesticide spray might vary from only some micrometres up to 1000 µm. Hence, this lens cannot be used for accurate droplet size measurements because of its big field of view and pixel size but it can be useful for droplet tracking over bigger distances and for measuring macro-spray characteristics.

For the K2/SC Long-Distance Microscope Lens at the settings described in Figure 1 multiple images were taken of the Halcon ceramic calibration plate (2.5 mm x 2.5 mm) ensuring to cover the whole field of view. The Xenon light was used as a front light to illuminate the front side of the plate. Images were processed with HDevelop software (MVTec Halcon Software, version 8.0, GmBH, München, Germany). Firstly, The FOV was measured with a ruler and this value was used to calculate the focal length. Then the FOV and focal length were entered in the software. The output from the software gave the exact focal length of 67 mm which corresponds to a pixel size of 8.23 µm for the 1280 x 1024 pixel images. Corollary the image size is 10.5 mm x 8.4 mm. Furthermore, no significant distortion was found with the calibration software. Consequently, the image acquisition set-up with the Microscope lens can be used to determine droplet sizes of 8.23 µm. Moreover, the droplets at 6 µs exposure time move less than a pixel between the frames which ensure no blurring effect.

CONCLUSION

The development of an imaging system for single droplet characterization was presented using a high speed camera. Different lenses, diffusers, light sources and settings were tested. The different imaging systems were evaluated using image analysis statistics based on the image quality parameters, the light stability and the droplet measuring accuracy using both images with and without a droplet produced with a single droplet generator.

The experiments have shown the necessity for having a good image acquisition and processing system. The optimal set-up for measuring droplet size and velocity consisted of a high speed camera with a 6 µs exposure time, a microscope lens at a working distance of 43 cm resulting in a field of view of 1.0 cm x 0.8 cm and a Xenon light source without diffuser used as a backlight. Besides, a similar system could be used for droplet impact characterization (Reichard *et al.*, 1998; Massinon *et al.*, 2012)

However, for measuring macro-spray characteristics as the droplet trajectory, the spray angle and the spray shape, a Macro Video Zoom lens at a working distance of 14.3 cm with a bigger field of view of 7.5 cm x 9.5 cm in combination with a halogen spotlight with a diffuser and the high speed camera can be used. With this system, attention should be paid to the light stability and for this reason; an AC/DC convertor should be used.

Future work should be done focusing on the droplet measuring accuracy (like sub-pixel accuracy, calculating depth of field, etc.) because of the small sized and fast droplets in a real spray.

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LITERATURE

GONZALEZ R.C., WOODS R.E., EDDINS S.L. 2004. Digital Image Processing Using Matlab. *New Jersey: Ed. Pearson Prentice Hall*.

HARALIC R. M, SHANMUGAM K, DIEINSTEIN I. 1973. Textural Features for Image Classification. *IEEE Transactions on systems, man and cybernetics,* **SMC-3**, No. **6**:610-621.

HIJAZI B, DECOURSELLE T, VULGARAKIS MINOV S, NUYTTENS D, COINTAULT F, PIETERS J. G. *et al*. 2012. The Use of High-Speed Imaging Systems for Applications in Precision Agriculture, *New Technologies – Trends, Innovations and Research (INTECH)*.

INFINITY PHOTO OPTICAL COMPANY. Photo-Optical Company. 2009. Model K2/SC Long-Distance Microscope System.

KIM H. H., KIM J. H., OGATA A. 2011. Time-resolved high-speed camera observation of electrospray. *Journal of Aerosol Science,* **42**: 249-263.

LAD N, AROUSSI A, MUHAMAD SAID M.F., 2011. Droplet size Measurement for Liquid Spray using Digital Image Analysis Technique. *Journal of Applies Science,* **11***:* 1966-1972.

MASSINON M., LEBEAU F., 2012. Experimental method for the assessment of agricultural spray retention based on high-speed imaging of drop impact on a synthetic superhydrophobic surface. *Biosystems Engineering,* **112***:* 56-64.

REICHARD D. L., COOPER J. A., BUKOVAC M. J., FOX R. D., 1998. Using a videographic system to assess spray droplet impaction and reflection from leaf and artificial surfaces. *Pesticide Science,* **53***:* 291-299.

RIEFLER N., WRIEDT T., 2008. Generation of monodisperse micron-sized droplets using free adjustable signals. *Particle and Particle Systems Characterization,* **25***:* 176-182.

ULMKE H., WRIEDT T., BAUCKHAGE K., 2001. Piezoelectric droplet generator for the calibration of particle-sizing instruments. *Chemical Engineering and Technology,* **24***:* 265-268.