

Evaluating droplet distribution of spray-nozzles for dust reduction in livestock buildings using machine vision

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Abstract: Previous studies have demonstrated the negative effects of sub-optimal air quality on profitability, production efficiency, environmental sustainability and animal welfare. Experiments were conducted to assess potential environmental improvement techniques such as installing oil-spraying systems in piggery buildings. The developed spray system worked very well and it was easy to assemble and operate. However, before selecting the most suitable spray heads, their capacity to uniformly distribute the oily mixture and the area covered by the spray heads had to be assessed. Machine vision techniques were used to evaluate the ability of different spray heads to evenly distribute the oil/water mixture. The results indicated that the best coverage was achieved by spray head No.4 and spray head No.1 which covered 79% and 67% of the target area, respectively. Spray distribution uniformity (variance) value was the lowest for spray head No.4 (0.015). Spray head No.3 had the highest variance value (0.064). As the lowest variance means higher uniformity, nozzle No.4 was identified as the most suitable spray head for dust reduction in livestock buildings.

Keywords: spray head, livestock buildings, dust reduction, machine vision, spray distribution uniformity, animal welfare

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1 Introduction

Recent studies indicate that sub-optimal air quality could be associated with reduced production efficiency in pigs^[1,2] and increased occupational health and safety (OH&S) risk for humans^[3]. Airborne dust may contain noxious gases, bacterial and fungal toxins that appear to enhance both the prevalence and severity of respiratory diseases in pigs^[2,4]. Dust may also aid the spread of infectious diseases^[5]. A number of studies have been conducted to develop strategies for reducing dust concentrations in different livestock buildings^[6]. For

example, spraying of water and oil mixture might be used to reduce the concentrations of airborne dust particles in a variety of livestock buildings^[7-9]. Information on the general design concept of oil spraying systems has been published previously^[7,10,11]. However, an important aspect of designing appropriate oil spraying systems is to evaluate the suitability of spray nozzles to uniformly distribute the oil/water mixture.

To our knowledge, there is no evidence in the literature that the design of spray nozzles (on their own right) would influence the level of dust reduction, as it mainly depends on the oil distribution. Spray nozzles however, do influence the evenness of oil distribution, which will determine the efficiency of the system. Thus, the specific aim of this study was to use machine vision techniques to assess (1) the coverage and (2) evenness of droplets produced by the selected spray heads to provide an objective assessment of the performance of different nozzles. In turn, this would enable livestock managers

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to objectively assess the suitability of spray heads used for dust reduction purposes in different livestock buildings.

2 Materials and methods

2.1 General description of the study and data collection

The present study was implemented at the Roseworthy research piggery (University of Adelaide) to practically evaluate oil-spraying systems in terms of their components, installation and maintenance requirements. An automated oil-spraying system was assembled simply and cheaply from commercially available components. As part of this larger evaluation study, the different spray-heads were also evaluated in terms of their ability to uniformly cover an area by the oil/water mix. The main considerations were: (1) the evenness of liquid distribution and (2) area coverage.

The spray-heads were first installed at a standardized position of the research piggery. Water-sensitive papers are widely utilized to evaluate the uniformity of spray coverage. It should be noted that these papers are not only sensitive to spray droplets but also to high relative humidity of the environment as they can turn blue under high humidity conditions (i.e. >85%). This makes them unreadable; therefore, it is recommended not to use them under high humidity conditions^[12,13]. Moreover, stain size on the paper continuously increases even after two months of the application^[14]. As a result, very large butcher papers were placed around the spray heads on the floor to cover the expected spray coverage area. Water mixed with standard food dye was sprayed on the papers via the different spray heads using a standardized spraying time (5 min). Water pressure was also standardized by using the same water pump (Franklin Electric, Dandenong, Victoria, Australia) during all spraying events. After each spray event, a number of pictures were taken using a digital camera (PowerShot, Cannon Australia, Sydney, Australia). Pictures were taken without the aid of any fixtures or support systems at the approximate height of 1.70 m. The casual nature of picture acquisition was maintained purposely, as it was envisaged that pictures will be taken on farms in the

future by untrained operators. Thus, the main aim of the study was to develop a simple, but robust image and data analysis system that will enable the reliable processing of images of the future that were acquired under less than ideal conditions. These pictures were further processed using image analysis techniques.

2.2 Image processing

First, the intensity of the images in the three channels (Red, Green, Blue; RGB) was enhanced by remapping image values in these channels. For this purpose, the visual quality of images was improved by applying a histogram equalization technique to enhance the quality of areas of interest^[15]. Histogram equalization was also used to improve the global contrast aspect of the images.

After image enhancements, K -means^[16] clustering was applied that aimed at partitioning n observations into the user specified k clusters via a two-phase iterative process. Similarly, clustering algorithm was used to determine the natural spectral groupings present in the data set. The algorithm arbitrarily seeded the number of cluster centres in the multidimensional measurement space. Each pixel in the image is then assigned to a cluster that arbitrary mean vector is closest. The procedure was continued until there was no significant change in the location of mean vectors between successive iterations of the algorithms^[17]. In this study, two clusters were defined, one for background and one for the area covered by the droplets. K -means cluster algorithm is presented by Equation (1):

$$W(C) = \sum_{k=1}^K N_k \sum_{C(i)=k} \|x_i - m_k\|^2 \quad (1)$$

where, m_k is the mean vector of the k^{th} cluster; N_k is the number of observations in the k^{th} cluster. Each observation (vector x_i) was assigned to one and only one cluster. Dissimilarity was measured by Euclidean distance metric. One of the most popular heuristics for solving the K -means problem is based on a simple iterative scheme for finding a locally minimal solution. The various steps of an iterative version of the algorithm areas follows: (1) to compute the intensity distribution (also called the histogram) of the intensities, (2) to initialize the centroids with k random intensities, (3) to repeat the following steps until the cluster labels of the image do not change

anymore and finally (4) to cluster the points based on distance of their intensities from the centroid intensities using Equation (2):

$$C_i = \arg \min \{ \|x_i - m_k\|^2 \} \quad (2)$$

Compute the new centroid for each of the clusters using Equation (3):

$$m_k = \frac{\sum_{k=1}^m 1\{c_k = j\} x_k}{\sum_{k=1}^m 1\{c_k = j\}} \quad (3)$$

As an example, the result of image processing of one of the nozzles (Spray head No.2) is shown in Figure 1. Figure 2a shows the original picture taken, while Figure 2b shows the result of clustering after applying the K-means technique. The main advantages of this technique are that the measurement and analysis can be performed in a very short time and subjective human error (which is almost unavoidable in manual sizing and counting) can be eliminated.



Figure 1 Different spray heads used during this study and the respective spray patterns



a. Original image



b. Clustering results

Figure 2 Results of image processing

2.3 Uniformity and occupied area measurements

After the binary images were created, images were divided into 24 equal sections. The occupied area on each part was calculated by Equation (4):

$$OA_i = \frac{\sum_{x(i)} \sum_{y(i)} C(x, y, i)}{\sum_{x(i)} \sum_{y(i)} T(x, y, i)} \quad (4)$$

where, $x(i)$ and $y(i)$ are the co-ordinates of the image pixels at i^{th} sub-window; $C(x, y, i)$ area which is covered by droplet at sub-window i^{th} ; $T(x, y, i)$ whole area at sub-window i^{th} . Variance of these 24 sub-windows was calculated and considered as a uniformity index. Sum of the all sub-window occupancy divided by the whole area was considered as an occupied area index for whole image.

3 Results and discussion

3.1 Occupied area and spray distribution uniformity

The occupied area and its variance for 24 sub-windows deposited on the paper target surfaces are given in Table 1. The best coverage (occupied area) was achieved using spray-head No.4 followed by spray head No.1 (78.7% and 70.3%, respectively). Uniformity of droplet distribution is the most important indicator of the nozzle performance^[18]. In most research, uniformity

of droplet distribution of spray nozzles have been identified in the laboratory using ‘patternator’^[19-23]. In another study, water sensitive papers were scanned at resolution of 600 dpi and saved as gray-scale images. Spray coverage was determined by UTHSCSA Image Tool 3.0. For each replication of the experiment, mean data at the top, middle and bottom of the target and their standard deviation (SD) was computed. Spray distribution uniformity was determined as a function of coefficient of variance (CV%)^[24]. In this study, spray distribution uniformity (variance) was also calculated automatically. Variance values for the spray-head No.4 and No.1 were lower than those of other nozzles (Table 1). The smallest value was found for the spray-head 4 (0.015). Spray heads No.3 and No.2 had the highest variance; 0.064 and 0.052, respectively. Since, the lowest variance means higher uniformity, nozzles No.4 and 1 showed the best potential for dust reduction.

Table 1 Descriptive statistics for the different spray heads

	No.1	No.2	No.3	No.4
Mean coverage area/%	70.3	19.3	12.1	78.7
Standard error	3.6	4.7	5.2	2.6
Standard deviation	17.8	22.8	25.3	12.6
Coefficient of Variation/%	25.32	118.13	209.1	16.01
Sample variance	3.2	5.2	6.4	1.6
Range/% of coverage area	66.5	65.3	85.5	57.6
Minimum	29.2	0.0	0.0	42.4
Maximum	95.6	65.3	85.5	100.0

The results of occupied area in 24 sub-windows for the nozzles are shown in Figure 3. It can be seen that nozzles No.1 and No.4 are more uniform than the others. The results are in line with variance of sub-windows presented in Table 1. Moreover, as shown in Figure 3, coverage for nozzles No.2 and No.3 areal most zero in most parts of the target surface which make these nozzles unsuitable for dust reduction compared to nozzles 1 and 4. Generally, the quality of spray application in the field is usually measured by collectors (e.g., water sensitive paper or Kromekote® card) attached to selected target areas and inspected after spraying^[25,26]. Imaging or scanning devices are used to measure spots on the collectors and to calculate the size distribution, area covered, or other measures of spray-coverage quality. Spot sizes are very small for measurement when spot

density is too high, i.e., coverage is greater than 20%^[27]. Another descriptor that is illustrated in the Table 1 is ‘range’ which is the difference between maximum and minimum of area coverage. According to its definition, the lower values of range could be interpreted as improved uniformity. Although, in some cases, the difference between maximum and minimum of area coverage could be low, but maximum and minimum value did not lay in the appropriate range. For example, range value of nozzle No.2 is lower than nozzle No.1, but maximum and minimum values of area coverage of this nozzle are worse than nozzle No.1.

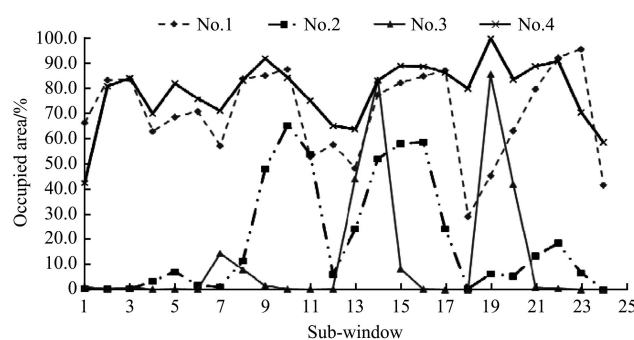


Figure 3 Results of occupied area in 24 sub-windows for the nozzles

Therefore, in order to correctly interpret uniformity indicators within given range values, more consideration was needed. Thus, a normal distribution Equation (5) was fitted on 24 sub-window of occupied area.

$$y = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \tag{5}$$

where, σ and μ are standard deviation and mean of vector x , respectively. According to the empirical rule of 68.95%-99.7%^[28] for nozzle head No.1 (Figure 4a) 68% of occupied areas were between 0.7-0.9. This means that most of the sub-windows were fully covered. However, for nozzles No.2 and No.3 (Figures 4b and 4c), 68% of data lied between 0-0.4. This can be interpreted as weak coverage of the target area. The results for nozzle No.4 were 0.5-0.9 (Figure 4d). Based on these results, nozzles No.1 and nozzle No.4 are suggested for dust reduction in livestock buildings. Previous research conducted at the Prairie Agricultural Machinery Institute (PAMI, Canada) under laboratory conditions using a stationary patternator, demonstrated that spray distribution is acceptable for up to 15% of the

variation^[29,30]. Thus according to the later study on the spray uniformity evaluation, nozzle No.4 has an acceptable uniformity.

Table 2 Mathematical parameters for normal distribution for the different spray heads

Parameters	No.1	No.2	No.3	No.4
σ	0.20	0.32	0.27	0.11
μ	0.69	0.21	0.15	0.81

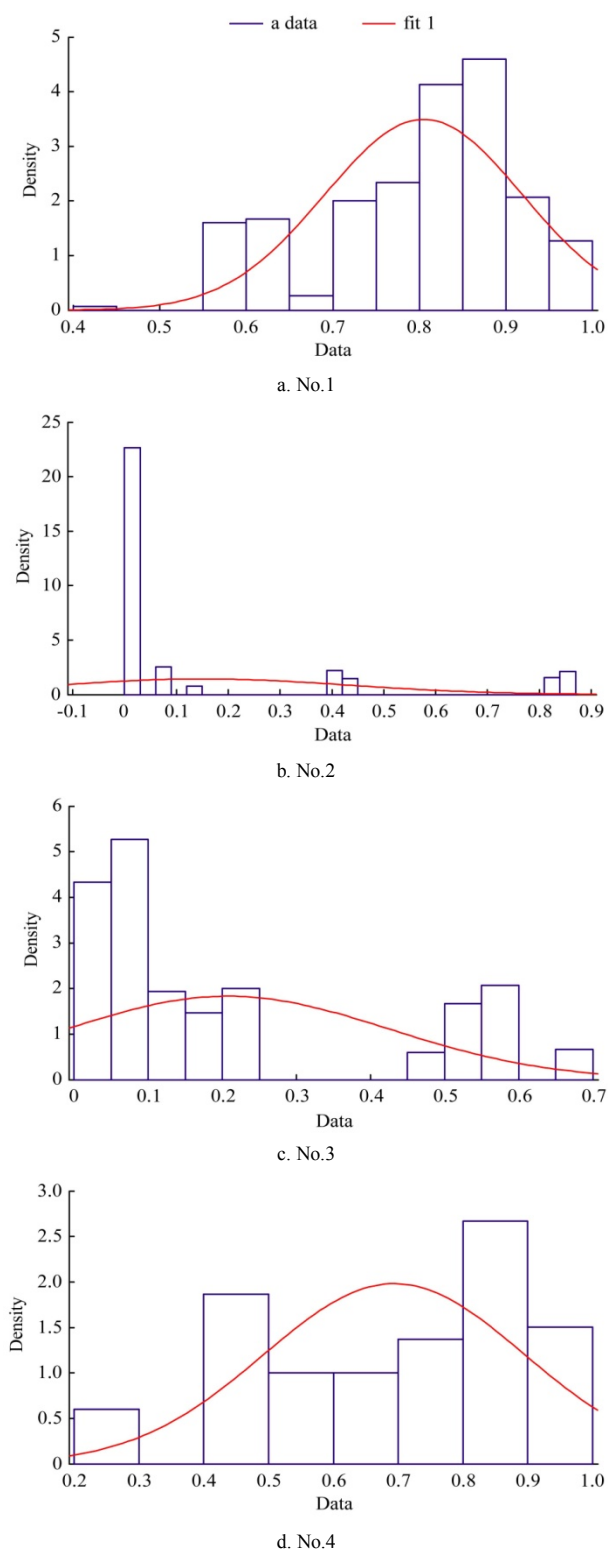


Figure 4 Normal distribution curves for nozzles

The method used in this study has the advantage of being a direct measurement technique to determine the coverage and uniformity of liquid droplet on a target area while the other assessment techniques have certain disadvantages^[31,32]. They require extensive training and are labour intensive^[33]. In addition, spectral characteristics are not always fully evaluated in visual interpretation efforts. This is because of the limited ability of the eye to discern total values on an image and the difficulty for an interpreter to simultaneously analyse numerous spectral pattern. Several spot size measurement systems and methods have been discussed in [34-40]. These systems are operated under laboratory conditions to provide valuable information about the quality of the spray coverage when comparing sprayers or treatments from one sprayer with different operating conditions. However, these systems are either too large or too slow to be easily applicable for spray coverage comparisons for growers at various training events or for comparative field studies. In a research, a Pulse-Width-Modulation-based continuously variable sprayer was developed using a proportional regulating solenoid valve^[41]. To measure spray distribution a spray sample table, including groove patternator with some V-shape liquid collecting troughs, cubical measuring cup, cup bracket, and supporting frame of the patternator to using spot measurement method were utilized. Measuring spray distribution by this method is very labour intensive. In another study, the feasibility of image analysis technique for determining the drop sizes from an irrigation spray nozzle were investigated^[42]. They stated that the photographs of the droplets on fly were taken using an ordinary camera and analyzed using digital image processing technique. The technique performed reasonably well in determining the drop size distribution of water spray from irrigation nozzle. Our study on the other hand develops new methods and introduces parameters using an image processing technique to measure spray quality under field conditions. These parameters and methods enable users to quickly determine spray deposits on collectors such as water sensitive paper and Kromekote® card.

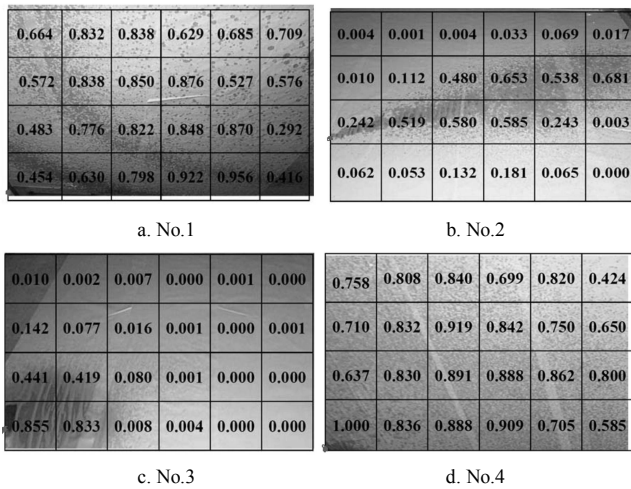


Figure 5 Occupied area, pictures of these four nozzles

4 Conclusions

In order to reduce dust in livestock industry, choosing suitable spray heads is of great importance; the capacity of evenly distributing the oily mixture and the area covered is one of the key features of these systems. Therefore, four spray heads were compared to evaluate the ability of uniform distribution of oil/water mixture by machine vision techniques. The analysis showed that the best coverage was achieved by spray heads No.4 and No.1 which covered 79% and 67% of the target area, respectively. Spray distribution uniformity (variance) value was the lowest for spray head No.4 (0.015). Spray head No.3 had the highest variance value (0.064). As the lowest variance means higher uniformity, nozzle No.4 was identified as the most suitable spray head for dust reduction in livestock buildings.

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