TECHNICAL NOTE:

DEVELOPMENT AND EVALUATION OF AN AUTOMATED SPRAY PATTERNATOR USING DIGITAL LIQUID LEVEL SENSORS

J. D. Luck, W. A. Schaardt, S. H. Forney, A. Sharda

ABSTRACT. *The purpose of this study was to develop and evaluate an automated spray pattern measurement system which utilized digital liquid level sensors to quantify the coefficient of variation (CV) for different nozzle configurations. The overall system was designed to measure nozzle effluent in 25 mm divisions from 38.1 to 76.2 cm in width for multiple nozzle configurations with a total patternator surface width of 3.05 m. The patternator surface and data collection system were designed and developed to achieve three primary goals: patternator surface division accuracy, data collection system accuracy, and data collection system repeatability. Patternator surface measurements indicated an average standard deviation of approximately 0.1 mm (0.4%) which would not contribute significantly to spray pattern CV estimates. To quantify the measurement accuracy, the automated system was compared to manual data collection using weights collected from graduated cylinders. Statistical analysis revealed no difference (p > 0.05) between CV estimates from the manual and automated data collection methods. The average difference in CV between the two methods was 0.15% which considered 12 tests per method. Repeatability was also a primary concern, the standard deviation among CV values for tests conducted with the automated system was only 0.35%. The evaluation of the system provided confidence that suitable results would be acquired for different nozzle configurations consisting of acceptable or relatively poor spray patterns.*

Keywords. *Pesticides, Spray boom, Sprayers, Spraying equipment.*

The efficient use of agricultural chemicals is a major issue in today's society. According to the last available agricultural census in 2012, the number of acres treated by chemicals, to control insects, weeds, nematodes, diseases, and growth in agricultural crops exceeded 400 million acres at a cost of over 16 billion dollars for 2012 in the United States alone (USDA NASS, 2012). The number of acres treated with chemicals shows the improvement chemicals applied with a uniform distribution to agricultural crops could save on cost of the material by reducing off-target application. The ability to quickly measure spray distribution uniformity has been approached in many different forms. These forms of measurement have progressed over time from manual observations to automated systems. Initially, observations were subject to human error of reading measurements on graduated cylinders. These manual observations were also very time-consuming. Attempts to automate this system included the use of load cells to measure the weight of liquid collected (Carpenter et al., 1988; Ozkan and Ackerman, 1992). These systems greatly reduced the labor required to collect data however, vibrations due to moving parts were problematic and most often only one nozzle body was used in the analysis. The results from the single nozzle body were then transposed onto one another to determine the spray distribution between multiple nozzles. Other systems used for spray distribution analysis include imagery (Zhang et al., 1994) and using tracers in the water or chemical to determine spray distribution (Liljedahl and Strait, 1959; Roth et al., 1979; Carpenter et al., 1988). The use of liquid level measurement sensors was determined to be a viable option (Antonio-Lopez et al., 2011) to determine spray distribution patterns using elapsed time over a fixed volume collected. This will be done with multiple nozzle bodies so that the user can determine the coefficient of variation of overlapping spray nozzles without having to superimpose the spray pattern from a single nozzle.

The overall goal of this research was to present an automated time-based method for measuring and analyzing spray pattern measurements from multiple nozzles.

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Specific project objectives were 1) to develop a computerized system for measuring spray pattern distributions at 25 mm increments using digital liquid level sensors and 2) to evaluate the ability of the system to provide accurate CV measurements using spray patterns of varying uniformity.

MATERIALS AND METHODS

SPRAY PATTERNATOR CONSTRUCTION

The spray patternator collection system was built according to specifications found in ASTM standard E641-01, Standard Methods for Testing Hydraulic Spray Nozzles Used in Agriculture (ASTM, 2006). The surface of the spray patternator was constructed from 0.16 cm stainless steel sheets positioned vertically on edge to split the nozzle effluent for measurement. The width of each sheet provided approximately 15 cm of depth to eliminate splash-back between the measurement grooves. The length of each sheet was 122 cm to allow for measurement from nozzles with wider distribution patterns (e.g., hollow-cone nozzles) as opposed to flat-fan nozzles. Troughs were formed at the bottom of each measurement groove by breaking each vertical sheet; a thin piece of weather stripping was placed between each trough and sheet which created a watertight seal between each groove. Nylon spacers 2.39 cm long were placed between each vertical sheet which divided the patternator into 25.4 mm grooves for measurement. Care was taken to ensure that the 2.54 cm spacing was maintained through the depth and length of the spray table. The vertical sheets, spacers, and weather stripping were clamped together with 0.635 cm rods that ran the width of the spray patternator. The table was designed for a 3 m length to allow measurements for configurations of multiple nozzles. The troughs were mounted on a tilting table frame 1.1 m above the ground to orient the channels at any angle between 0-10°from the horizontal plane using turnbuckles at the back of the table. A picture of the fabricated spray patternator can be seen in figure 1.

AUTOMATED MEASUREMENT SYSTEM DEVELOPMENT

The system for measuring effluent from each trough consisted of a 2.54 cm × 5.1 cm rectangular plastic tube 40.64 cm in height that was capped at the bottom. Two holes were drilled along the back side of each tube; the bottom hole was used for draining the tubes while the top hole was for placement of the liquid level sensors. The holes were drilled using a CNC milling machine to maintain consistent distances for each measurement tube. A normally closed solenoid valve (Part No. 7877K55, McMaster Carr, Columbus, Ohio) (fig. 2) was threaded and sealed in the bottom hole, 12 V DC were applied to the solenoid valve, to drain liquid collected in each tube after a test. The liquid level sensor (102101, Honeywell Inc., Morris Plains, NJ) (fig. 3) was threaded and sealed in the top hole of each collected tube.

The liquid level sensors required 5 V DC for power and returned a digital value of 1 when covered with water. An overflow opening (fig. 3) was drilled approximately 2.54 cm above the liquid level sensor on the front of each collection tube. A total of 30 tubes were constructed in this fashion and mounted next to each other on a mobile stand separated from the spray table to avoid dynamic interaction between the spray table and data collection sensor array.

Customized software was developed using LabView (v 11.0, National Instruments, Austin, TX) which utilized a data acquisition (DAQ) board (NI-USB-6343, National Instruments) to control the test platform and collect data. The data acquisition board was connected to a computer via a USB port and consisted of 48 digital inputs with eight analog input/outputs. System operating pressure was monitored by the DAQ system using a calibrated pressure transducer (PX309-100G5V, Omegadyne, Inc., Sunbury, Ohio) that supplied a 0 to 5 VDC output signal proportional to operating range for the pressure transducer (0 to 690 kPa). A 12 V DC relay (DC100D10, Crydom, San Diego, Calif.) was used to provide sufficient power to actuate the solenoid valves based on the analog output signal from the DAQ board. A graphical user interface (GUI) was developed within the software to prompt the

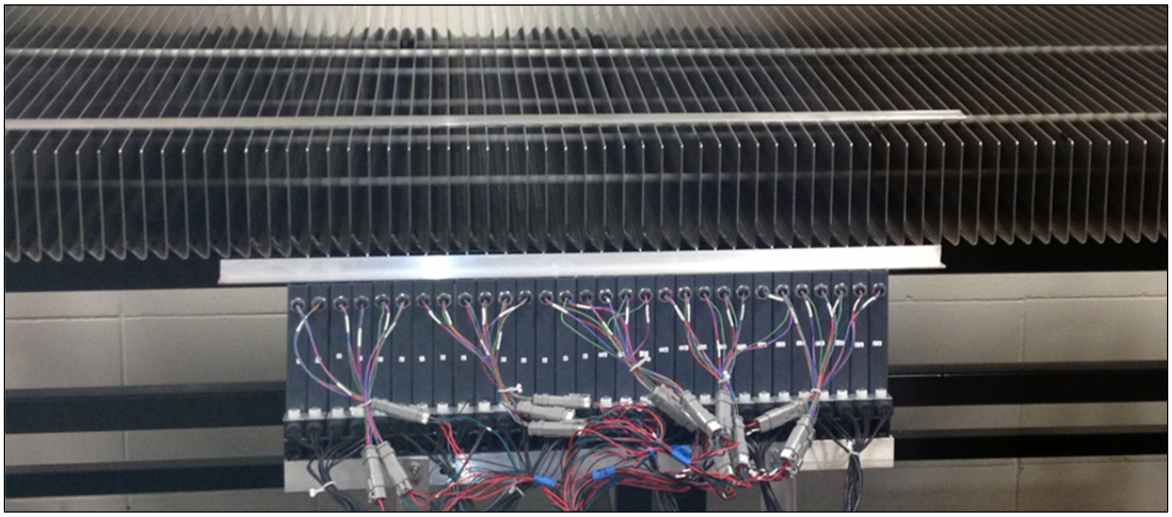

Figure 1. Spray table patternator (steel sheets divided by spacers) with electronic automated collection system positioned below the patternator surface.

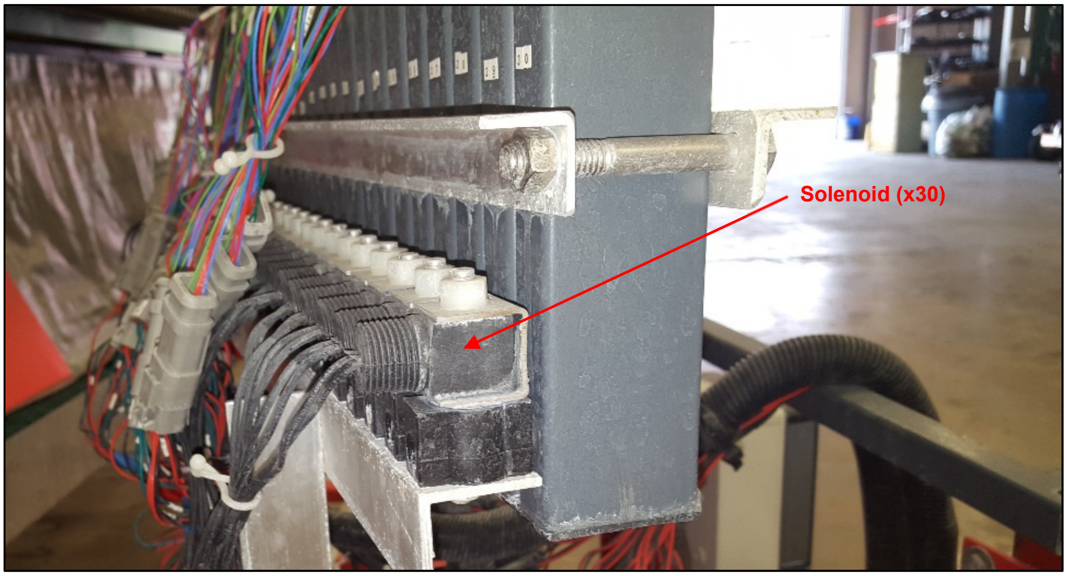

Figure 2. Solenoids on water collection tubes remained open until test was initiated, solenoids then closed to collect liquid.

user to enter test setup conditions prior to initializing a test. Three separate configurations were presented to the user to allow for collection of 15, 20, or 30 tubes; common nozzle spacing widths for U.S. spraying systems. The system was allowed to run for at least 1 min with the solenoid valves open to reach a steady state before initializing a test. When each test was initialized, the software would simultaneously remove solenoid power (closing all valves), start an internal timer, and begin monitoring digital input signals from the liquid level sensors. Ancillary inputs for testing read by the software included analog inputs for pressure or flow sensors used during tests. The software would continue monitoring these signals throughout the test specified by the user. When a HI (1) signal was read by the software for a particular collection tube, the current time was recorded for that specific tube. These values were continually logged until all tubes (for test configurations of 15, 20, or 30 tube collection widths) had registered a HI signal. At that time, the software automatically powered the solenoid valves allowing them to drain the collection tubes and a .csv file was generated in MS Excel summarizing test data. The summary included any test setup conditions entered into the GUI by the user, the elapsed fill time for each tube, other sensor (e.g., pressure) data collected during the test. The flow rate (mL min^{-1}) was calculated by dividing the estimated volume of each tube by the fill time. An estimate of CV from these data was then calculated for the spray pattern using equation 1 (as reported by Ozkan, et al., 1992). The coefficient of variation (CV) is commonly used to quantify the uniformity of spray systems; higher CV values indicate poor uniformity in the spray pattern.

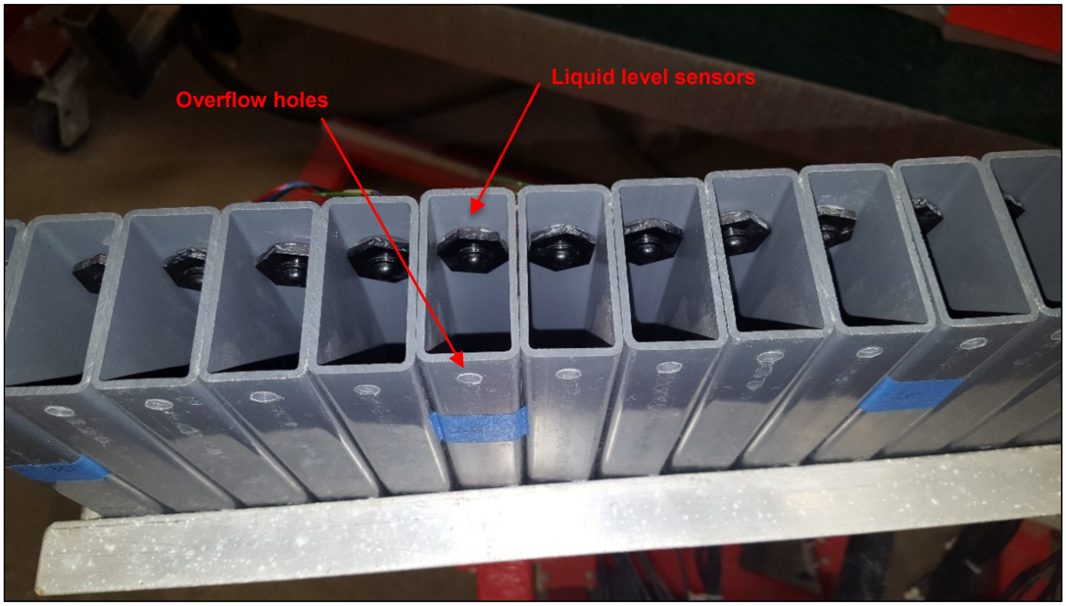

Figure 3. Liquid level sensors mounted on collection tubes with overflow holes to allow water to drain.

$$Coefficient\ of\ Variation\left(CV\right)\% = \left(\frac{\sqrt{\frac{\sum\left(X_i-\bar{X}\right)^2}{n-1}}}{\frac{\sum X_i}{n}} \right) \times 100 \qquad (1)$$

where

x_i = flow rate (fixed volume divided by fill time) at the ith sample of the spray pattern width (mL min^{-1}),

$\bar{x}$ = mean flow rate (mL min^{-1}) to fill all collection volumes across the spray pattern width,

n = number of measurements.

TESTING AND EVALUATION PROCEDURES

Carrier flow was supplied by a smooth-flow helical rotor pump (101B, Oberdorfer Pumps, Syracuse, N.Y.) driven by a 0.56 kW 115 V motor operating at 1725 rpm. Carrier pressure was controlled with a pressure regulating (PR) valve (23120, TeeJet Technologies, Wheaton, Ill.) which could be set by the operator and monitored with a manual pressure gage. Once the nozzles were placed above the patternator in the desired configuration, data collection could be initiated by the user. A set of tests were designed to provide information on the ability of the automated collection system to collect accurate pattern data.

Three main goals were considered for ensuring accurate data collection: accurate division of the spray deposition, accurate measurement of fluid collected for each division, and repeatability for multiple tests.

PATTERNATOR SURFACE DIVISION ACCURACY

To check for division separation accuracy, three measurements were taken between each stainless steel sheet across the center of the patternator, then at 1 ft deviations from the center using a micrometer. The mean and standard deviation (SD) of measurements were calculated and the CV was calculated by dividing the SD by the mean for all measurements across the patternator. The goal was to achieve a CV of less than 0.5% across the patternator.

PATTERNATOR MEASUREMENT ACCURACY

Tests were also designed to compare the spray pattern CV estimates versus manually collecting nozzle flow rates from each collection trough. After nozzles were configured above the spray patternator, three replicated data sets were collected using the automated system. The automated collection system was removed and flow from each collection trough was gathered into graduated cylinders. The water from each graduated cylinder was then weighed to calculate the spray pattern CV using equation 1 with weights from each graduated cylinder. The spray pattern CVs between the automated collection system and the manual collection were then compared. Five nozzles (XR11005, Teejet, Wheaton, IL) were placed above the patternator and the automated collection system was centered below the middle nozzle and the program was configured to collect the full (30 trough) system width. Four different nozzle configurations were tested: all nozzles on at 50.8 cm height, the center nozzle off with all other nozzles on at 63.5 cm height, all nozzles on at 76.2 cm height, and center nozzle off with all other nozzles on at 76.2 cm height. The purpose of multiple nozzle configurations was to test spray patterns that could be considered both acceptable and potentially poor in quality. Three replicates of spray pattern CV were collected for each nozzle configuration and test system (i.e., manual or automated method). Statistical analyses were conducted to evaluate if there were significant differences between the two methods for assessing spray pattern CVs. Statistical Analysis Software (SAS, v9.2, SAS Institute, Cary, N.C.) was used for this purpose, the *proc mixed* function was used to compare result CVs versus collection method (i.e., treatment) type for the four different nozzle configurations. The treatments were considered significant at an alpha value of 0.05.

PATTERNATOR MEASUREMENT REPEATABILITY

A final assessment for the automated spray pattern collection system was to determine repeatability among common test configurations. Replicated data from the measurement accuracy tests were used to assess repeatability in CV estimates from the automated system. The SD was calculated from the three replicate tests for CVs using the automated system. The result was four different estimates of SD (one for each nozzle configuration) which were averaged to determine what variation might be expected from the automated system from test to test.

RESULTS AND DISCUSSION

The fabrication of the patternator and development of the data acquisition system for measurement resulted in a platform that was capable of rapidly collecting spray pattern data. In most cases, a pattern assessment could be made in one to two minutes (depending on nozzle flow rates) and the Excel spreadsheet generated from the system contained individual measurement times for each tube along with a calculated CV value. Output from the automated spray patternator system was successfully logged for each test dataset. Compared to the manual weight-based measurements, (which took approximately 8 to 10 min to record and calculate a CV), the automated system accomplished the same task in about one-fourth of that time.

PATTERNATOR MEASUREMENT ACCURACY

Spray patternator surface measurements to assess collection width variations revealed that this would not contribute greatly to errors in pattern uniformity estimates. The target for each division was 25 mm; the SD calculated across all of the collection widths (three measurements taken per width) was 0.1 mm, or 0.4% of the desired width. While this was seen as a minor variation from the desired collection widths, it should be noted that deviations in collection width could highly impact assessments of spray pattern. Every effort should be taken to minimize any differences in spray collection widths for accurate pattern measurement.

PATTERNATOR MEASUREMENT ACCURACY

Results of the statistical analysis to determine if the automated system could perform similarly to manual measurements of fluid collected are shown in table 1. Based on these data, there was no significant difference between the two measurement methods across each of the four tests. The average difference in CV for each of the four tests was 0.15%, which consisted of average data for 12 tests with each system. The most pronounced difference in spray pattern CV occurred during the test with four spray nozzles at 76.2 cm above the spray patternator surface; a difference of 0.3% was noted. These results indicated that the automated system performed adequately when compared to a manual measurement technique for fluid collected from the patternator.

PATTERNATOR MEASUREMENT REPEATABILITY

A summary of test results for repeatability assessment are shown in table 2. Overall, the standard deviation for the four tests (three replicates per test shown in table 2) averaged 0.35%; SD values ranged from 0.2% to 0.7%. While no data has been published to determine what would be considered acceptable in terms of patternator repeatability, we believe that an average deviation in CV of less than 0.5% would be satisfactory. Results from table 2 indicated that while some data could exceed this threshold from time to time, averaging values from multiple tests would reduce variation in CV estimates greatly.

Table 1. Summary of statistical analysis results for comparison between manual and automated CV estimates.

	Nozzle Test Configuration			
Collection System	No. of Nozzles Spraying	Nozzle Height (cm)	Average Spray Pattern CV (%)[a]	CV Difference from Manual (%)
Manual	5	50.8	5.5[a]	
Automated	5	50.8	5.3[a]	-0.2
Manual	4	63.5	9.4[b]	
Automated	4	63.5	9.3[b]	-0.1
Manual	5	76.2	4.9[c]	
Automated	5	76.2	4.9[c]	0.0
Manual	4	76.2	6.8[d]	
Automated	4	76.2	7.1[d]	+0.3

[a] Capital letters indicate significant difference in average CV values for manual versus automated collection measurements ($p \leq 0.05$).

Table 2. Summary of automated data collection replicate test with SD values for repeatability assessment.

Nozzle Test Configuration					
No. of Nozzles Spraying	Nozzle Height (cm)	Test 1 CV (%)	Test 2 CV (%)	Test 3 CV (%)	SD (%)
5	50.8	5.3	5.2	5.5	0.2%
4	63.5	4.7	5.2	4.9	0.3%
5	76.2	6.4	7.9	7.2	0.7%
4	76.2	9.2	9.2	9.6	0.2%

CONCLUSIONS

An automated spray pattern data collection platform was developed and tested at the University of Nebraska-Lincoln. The overall system was designed to measure nozzle effluent in 25 mm divisions from 38.1 to 76.2 cm in width for multiple nozzle configurations with a total patternator surface width of 3.05 m. The patternator surface and data collection system were designed and developed to achieve three primary goals: patternator surface division accuracy, data collection system accuracy, and data collection system repeatability. Patternator surface measurements indicated an average standard deviation of approximately 0.1 mm (0.4%) which would not contribute significantly to spray pattern CV estimates. To quantify the measurement accuracy, the automated system was compared to manual data collection using weights collected from graduated cylinders. Statistical analysis revealed no difference ($p > 0.05$) between CV estimates from the manual and automated data collection methods. The average difference in CV between the two methods was 0.15% which considered 12 tests per method. Repeatability was also a primary concern; the standard deviation among CV values for tests conducted with the automated system was only 0.35%. The evaluation of the system provided confidence that suitable results would be acquired for different nozzle configurations consisting of acceptable or relatively poor spray patterns.

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