7-2015

DETECTING GRAIN FLOW RATE USING A LASER SCANNER

Hossein Navid
University of Tabriz, navid@tabrizu.ac.ir

Randal K. Taylor
Oklahoma State University

Arzu Yazgi
Ege University

Ning Wang
Oklahoma State University

Yeyin Shi
University of Florida, yshi18@unl.edu

See next page for additional authors

Authors
Hossein Navid, Randal K. Taylor, Arzu Yazgi, Ning Wang, Yeyin Shi, and Paul Weckler

TECHNICAL NOTE:

DETECTING GRAIN FLOW RATE USING A LASER SCANNER

H. Navid, R. K. Taylor, A. Yazgi, N. Wang, Y. Shi, P. Weckler

ABSTRACT. *Detecting and measuring mass flow is fundamental to many applications in agricultural engineering. Material handling, food processing, fertilizer spreading, and yield monitoring in combines are examples where mass flow measurement is needed. Methods for measuring material flow have used load cells, optical sensors, radiometric sensors, and many other techniques. The objective of this study was to develop a system to measure material (grain) flow using a laser line scanner. A laser line scanner measures the distance between the sensor and objects based on the time-of-flight principle. In this study, it was used to measure grain flowing from a stationary bin. A sliding gate at the bottom of the bin was used to adjust the grain flow. Experiments were conducted at six grain flow rates with three replications. The results showed the ability to detect the grain flow and measure grain flow rates up to approximately 5 kg s^{-1} for 45 cm of flow width (with R^2 = 0.97). Measurement of flow rates greater than 5 kg s^{-1} was not possible. We found a linear relationship between grain flow rate and the RMSE of the laser line scanner signal (R^2 = 0.91).*

Keywords. *Harvester, Laser, Mass flow, Wheat.*

Detecting and measuring agricultural material flow is important in a wide range of applications in agricultural engineering, such as material handling, food processing, yield monitoring, and fertilizer spreading. In these applications, flow rate is determined by measuring material mass or volume as a function of time. Although different materials require detection, the methods for a given material type (e.g., granular) can be similar. Researchers have developed methods such as impact-based sensors, radiometric-based sensors, and optical methods to detect and measure material flow. Abdul Rahim and Green (1998) studied an optical-fiber sensor (containing 32 light sources and 32 light detectors) in a tomographic measurement system to measure the flow of dry solids (sand or 3 mm plastic chips) in a gravity-drop system with an 81 mm diameter pipe and pneumatic conveyor. Their results showed linearity between flow rate and output voltage up to 0.5 kg s^{-1} mass flow rate. They concluded that increasing the number of optical-fiber sensors resulted in better accuracy, and the sensors had a linear response to the increased concentration of solids.

Arslan et al. (2000) used x-ray techniques for grain flow measurement. They used an x-ray generator and image intensifier to detect grain flow. They related the mass flow rate to the measured x-ray gray-scale intensity and found a correlation coefficient of 0.99 for the measurements of corn flow rates up to 6 kg s^{-1}. However, they did not mention output gate profiles. They also required 2 mm thick lead foil or 5 mm steel to shield the photon energy. Swisher et al. (2000) designed and used an optical sensor to measure granular fertilizer flow in an airstream. Their system contained a trapezoidal chamber with a light source on one side and a 32-element photodiode array on the opposite side. The falling granular material broke the light beam to generate signals to be recorded. The researchers concluded that the average particle mass affected calibration more than the product type, density, or average particle size.

Grift et al. (2001) developed a system to measure mass flow of granular fertilizer materials in aerial spreader ducts. They used an optical sensor in low-density to high-density flow regimes. To obtain different flow densities, they dropped 2000 particles from four different heights (30, 46, 54, and 101 cm). Tests were conducted with 4.45 mm diameter particles. This method could measure the flow with 2% to 3% accuracy. Na et al. (2005) used an array of LED and phototransistor sets to measure the flow rate of four crops. They obtained a relationship between crop flow and sensor outputs by counting the interrupted light. Unlike most load cell based systems, their photosensor system for measuring mass flow was unaffected by vehicle vibration.

Zhao et al. (2011) developed an indirect measurement method for separation loss in a laboratory grain threshing unit to find the relationship between separation loss and grain flow. They used a piezoelectric polyvinylidene fluoride (PDVF) film system to monitor the grain separation loss while harvesting three rice varieties. Feasibility testing during field operation in a combine indicated that their piezoelectric system was able to measure grain separation loss to

Submitted for review in December 2014 as manuscript number MS 11097; approved as a Technical Note for publication by the Machinery Systems Community of ASABE in July 2015.

The authors are **Hossein Navid, ASABE Member,** Associate Professor, Faculty of Agriculture, University of Tabriz, Tabriz, Iran; **Randal K. Taylor, ASABE Fellow,** Professor, Department of Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, Oklahoma; **Arzu Yazgi, ASABE Member,** Assistant Professor, Department of Agricultural Machinery, Ege University, Izmir, Turkey; **Ning Wang, ASABE Member,** Associate Professor, Department of Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, Oklahoma; **Yeyin Shi, ASABE Member,** Postdoctoral Associate, Citrus Research and Education Center, University of Florida, Lake Alfred, Florida; **Paul Weckler, ASABE Member,** Associate Professor, Department of Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, Oklahoma. **Corresponding author:** Hossein Navid, University of Tabriz, 29 Bahman Blud, Tabriz, Iran; phone: +98-41-33392782; e-mail: navid@tabrizu.ac.ir.

Vol. 58(5): 1185-1190 ISSN 2151-0032 DOI 10.13031/trans.58.11097

within 12% of the separation loss measured manually. Similarly, Liang et al. (2012) installed a piezoelectric sensor in an area under the separation concave to monitor separation loss in a tangential-axial flow combine harvester. They developed a mathematical model to analyze the distribution of mixed materials (grain and material other than grain) in the axial and radial directions of the threshing rotor. The results showed that their model could estimate the separation loss to within 3.4% of the actual loss.

Most optical systems available for granular material flow measurement have two components: a source or emitter and a sensor or detector. As an example, optical yield monitors have two parts and are installed on the clean grain elevator. In some agricultural machinery applications, such as inside the threshing or cleaning units of a grain combine, mounting and aligning both components is challenging. Thus, reflective sensors, such as a laser line scanner installed on one side, are desirable in these applications. In addition, some optical sensors have limited ability to detect small particles, whereas a laser line scanner does not have this limitation. Furthermore, the measurement accuracy, convenience, and reliability of laser technology in measurement also make it a favorable option for these applications. A laser scanner measures distance by sending a laser beam out to an object and measuring how long it takes to reflect back. The distance is computed by multiplying the time by the speed of light and dividing by 2. Lee and Ehsani (2008) applied laser scanners in precision agriculture to measure plant growth rate, tree count, 3D imaging, and other characteristics such as height, width, number and spacing of plants, and biomass density.

Saeys et al. (2009) estimated wheat density using a LiDAR sensor. During their tests, they put certain numbers of wheat heads on trays. These pre-controlled trays were placed on the ground and scanned using a laser scanner installed on a combine. They estimated crop density at different ground speeds and machine vibration levels with coefficients of determination greater than 0.80 between the standard deviation of laser penetration depth into the canopy and crop density. They concluded that crop density measurement was more robust against speed variation and vibration effects when using a high-frequency laser scanner. Jadhav (2010) used LiDAR to estimate the mass of fruit passing on the conveying system of a mechanical citrus harvester. He developed a system to scan the cross-sectional area to calculate the volume and thus the mass of the fruit.

Shi et al. (2013) developed a system based on a laser line scanning technique to measure plant location and spacing. The results showed that the laser scanner could detect stalks and determine crop spacing in areas with good weed control. The researchers also found good correlation between manually measured and laser measured plant spacing.

Despite the use of ground-based laser sensors in precision agriculture, little research has been conducted on crop flow detection using this technology. The objective of this study is to develop a system using a laser scanner to detect and measure grain flow.

Materials and Methods

The test apparatus contained a laser scanner, a grain bin with a sliding gate to deliver different grain flow rates, a dynamic weighing system to measure grain weight, a laptop to record and save data, a wooden wall to create a consistent background, and a control program developed using LabView (National Instruments, Austin, Tex.) (fig. 1). The points detected on the wooden wall were used as a baseline since they were well beyond the depth of the grain flow. The grain bin had an approximate volume of 0.2 m^3 with a sliding gate at the bottom that was used to adjust the grain flow. The gate opening was 450 mm long with a maximum width of 50 mm.

Data Acquisition

The data acquisition system contained a laser scanner and four load cells. The laser line scanner (LMS291, Sick AG, Waldkirch, Germany) measured the distance between the sensor and grain based on the time-of-flight principle. The scanned field of view was 100° with 0.25° resolution. Each scan interval resulted in 401 distance measurements

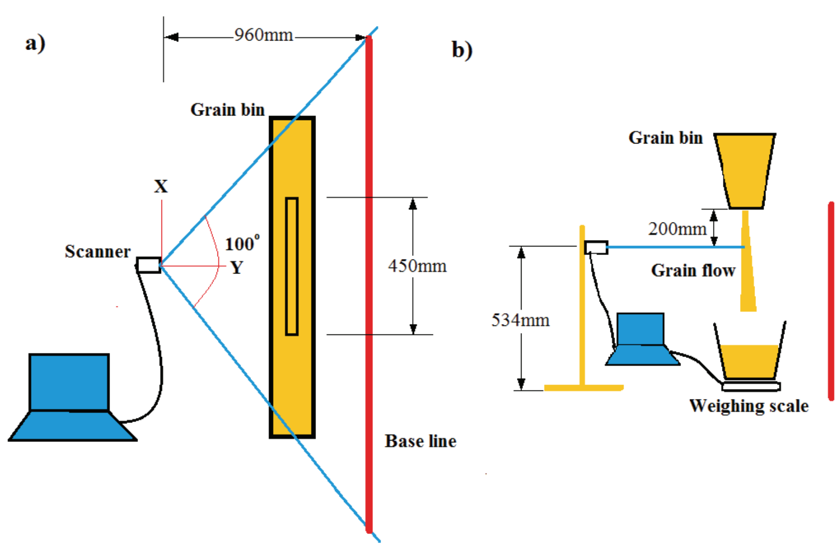

Figure. 1 Setup of the laser scanner and other components: (a) top view and (b) side view.

within 53 ms. The scanning frequency for the scanner was 75 Hz. The laser scanner was installed on a sliding system for height adjustment but was fixed at 534 mm from the floor during these tests. At this height, the laser line detected grain flow at 200 mm below the gate (fig. 1). An RS-422 connection configured at 500 kbps rate was connected to a serial-to-Ethernet convertor between the laser scanner and the laptop to ensure a good data transfer rate. The sampling frequency was 10 Hz.

The dynamic weighing system included four 22.7 kg (50 lb) capacity load cells (SSM, Interface, Scottsdale, Ariz.) connected through a summing junction box and a data acquisition card (DAQ). The load cells were calibrated with known weights at 10%, 25%, 45%, 60%, 70%, 80%, and 100% of load cell capacity to establish a linear relationship between measured voltage and actual loads.

A program developed in LabView was used to control the laser scanner, record and save data from both sensors (laser scanner and load cells), convert the laser position data from polar to Cartesian coordinates, and calculate the real-time weight. Data from the laser scanner and the load cells were recorded simultaneously with this program. The recorded data contained the position of the detected points, sampling time, and real-time grain weight. The data were processed to obtain the position data in Cartesian coordinates and the grain flow rate. The processed data were then saved in an Excel file for further analysis.

Experimental Setup

This experiment was conducted in the intelligent machine laboratory at Oklahoma State University in Stillwater, Oklahoma. The wheat grain sample had a 1000-kernel weight of 27.9 g and a bulk density of 1176.3 kg m^{-3}. The laboratory experiments were conducted with six grain flow rates achieved using the sliding gate on the bottom of the grain bin. All six flow rates were included sequentially in one test. Preliminary tests were conducted to determine the proper gate position for each desired flow rate. The data acquisition program was initiated, and the sliding gate was opened to the first position. After approximately 10 s, the gate was opened farther to the next position to obtain the second flow rate. This was repeated until the highest flow rate was achieved. Because the gate was controlled manually, repeatedly setting it to the exact location was not possible. Thus, there was some variability of flow rate among the targeted gate settings. However, the actual flow rate was measured with the load cell weighing system and correlated to the laser scanner readings. Figure 2 shows the measured flow rates of three replications.

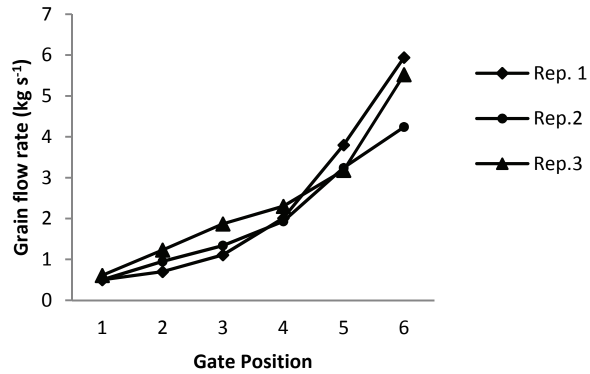

Figure 2. Flow rates at different gate positions for three replications.

Data Analysis

Data recorded from the laser scanner showing the location of the detected points were originally in polar coordinates. The origin of polar coordinate system was located at the laser scanner, and its direction was counter-clockwise. The points were converted to Cartesian coordinates with the center of the scanner as the origin. As shown in figure 1, the *X*-axis was parallel to the grain bin, and the *Y*-axis was perpendicular to the *X*-axis and increased with distance from the sensor. The transformed data for each replication were saved in an Excel spreadsheet. The Cartesian coordinates for a single scan at two flow rates are shown in figure 3. These data show the baseline of the wooden background at a distance of approximately 960 mm and also the magnitude and variability of the *Y* values for different flow rates. There was an observable difference between the laser scanner outputs for different flow rates. Higher flow rates resulted in smaller, less variable *Y* values

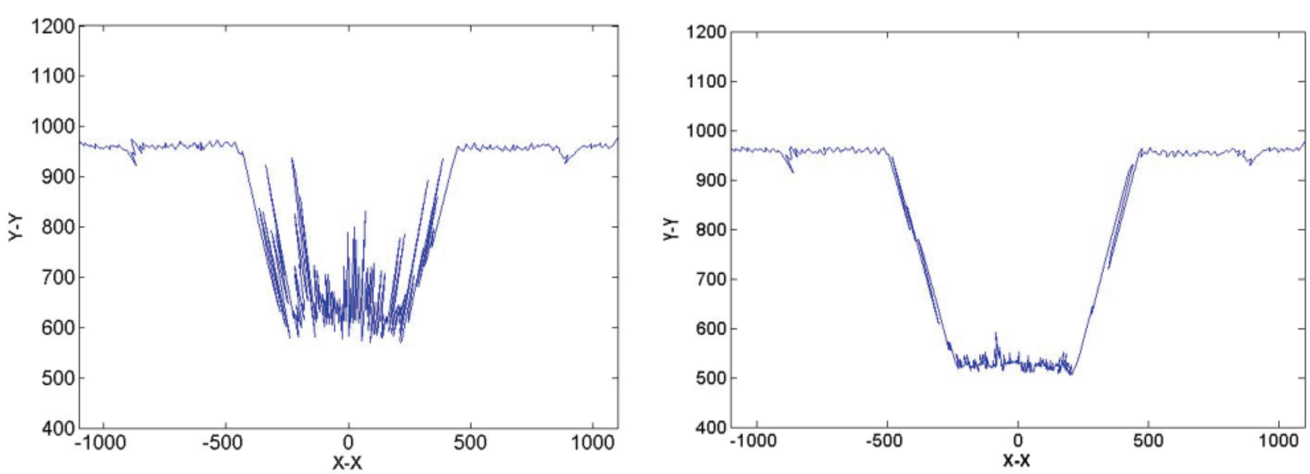

Figure 3. Scanner results in the *X*-*Y* plane after some preprocessing for low grain flow rate (left) and high grain flow rate (right).

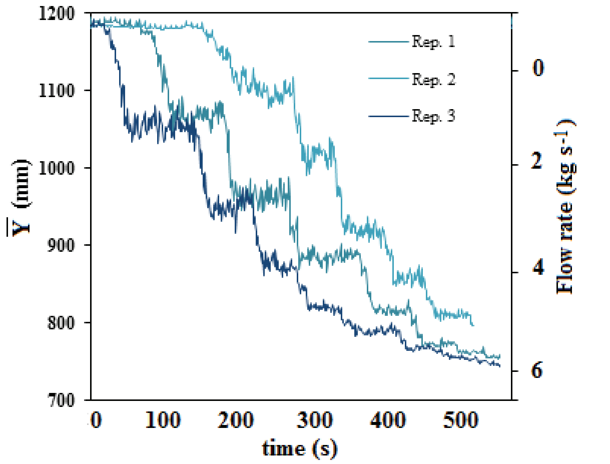

Figure 4. Mean $\bar{Y}$ values (detected) as a function of time for different flow rates within an individual test. Each horizontal step represents a specific flow rate.

because higher flow rates appear as a wall of grain. At lower flow rates, the laser penetrated the gaps in the grain flow, resulting in more variation in the Y values. For subsequent analysis, the data were filtered along the X-axis based on the field of view of the laser scanner and the width of the grain flow (-200 mm < X <200 mm). This threshold was selected because the grain bin opening length was 450 mm and investigation of the scanner outputs showed that the data between -200 mm and 200 mm were more consistent because of occasional disturbances observed along the outer edges of the scan. The Y values in this range were averaged for each sampling in each test. Figure 4 shows the mean Y values obtained in one test as a function of time. Each step in the graph relates to specific flow rate, and each point in the graph is the average Y value in -200 mm < X < 200 mm from one scan. Figure 4 clearly shows that different flow rates have different distances from the scanner, with greater flow rates having a lower distance.

Since the variability in the Y values appeared related to flow rate, some statistical parameters to describe this variation were calculated to estimate the grain flow rates. This observation was consistent with the results of Saeys et al. (2009), who used LiDAR to estimate crop density. They used the mean, median, and standard deviation of the laser data to describe crop density. The parameters evaluated in this study were the mean ($\bar{Y}$), root mean square error (RMSE), mean absolute error (MAE), and standard deviation (σ) and were calculated based the following equations for the Y values. Data were processed and the desired statistical parameters calculated in MATLAB R2013a:

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(Y_i - \bar{Y}\right)^2} \quad (1)$$

$$\bar{Y} = \frac{\sum Y_i}{N} \quad (2)$$

$$\text{MAE} = \frac{\sum_{i=1}^{N}\left|\left(Y_i - \bar{Y}\right)\right|}{N} \quad (3)$$

$$\sigma = \frac{\sum\left(Y_i - \bar{Y}\right)^2}{N} \quad (4)$$

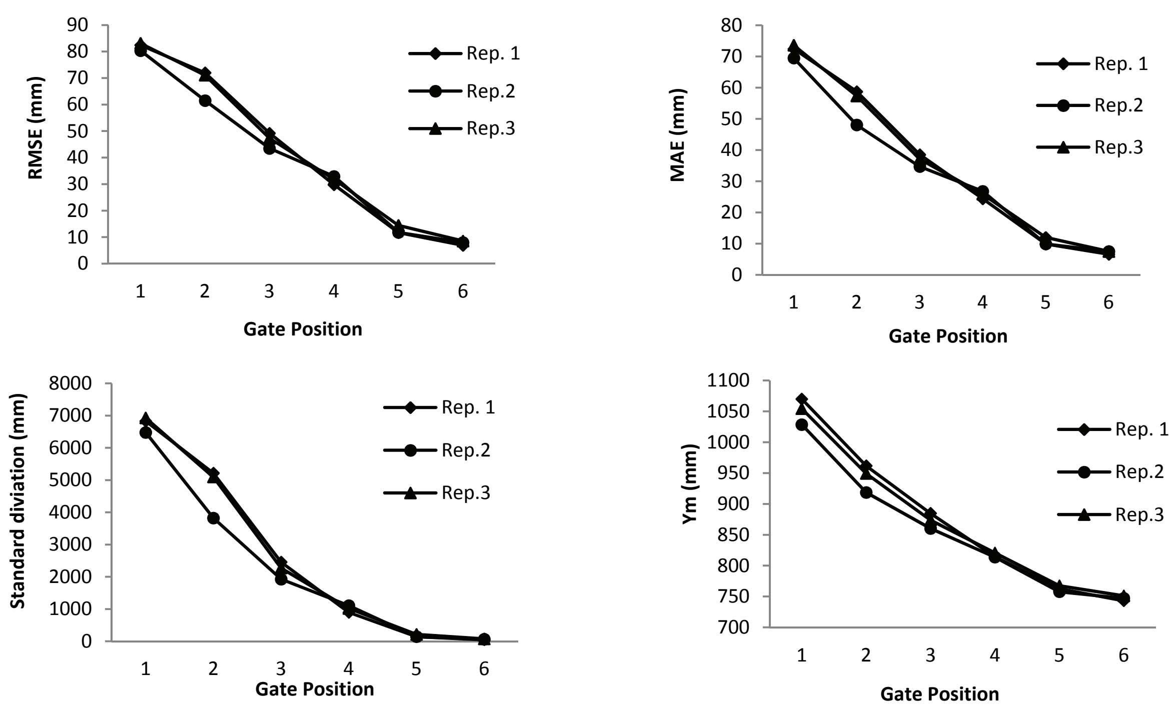

Figure 5. Results of statistical parameters vs. gate position.

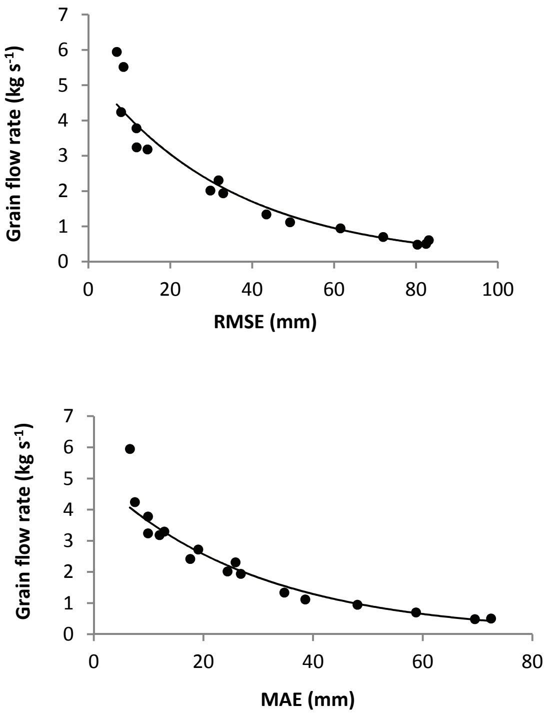

Figure 6. Grain flow prediction by RMSE and MAE.

RESULTS AND DISCUSSION

Based on the data obtained from the laser scanner, statistical parameters (RMSE, MAE, average distance, and standard deviation) were used to describe the grain flow rate estimation, as shown in figure 5. Each point in these graphs was obtained for all scans at a given flow rate. As shown in figure 5, all of the parameters related similarly to grain flow rate, and there was generally a consistent relationship between the gate position and the parameters. However, as discussed earlier, setting the gate position was somewhat arbitrary and difficult to repeat.

Because the subsequent analysis was based on measured flow rate, the data from replications were combined. The trend was clear for RMSE and MAE, and for these two parameters we obtained higher values for R^2 with flow rate than for the other parameters. Figure 6 shows grain flow rate as a function of these two parameters. An exponential equation provided the best fit between grain flow rate and these parameters (eqs. 5 and 6):

$$\dot{m} = 5.4505 \times e^{-0.029(\text{RMSE})},\ \text{R}^2 = 0.97 \tag{5}$$

$$\dot{m} = 5.1015 \times e^{-0.034(\text{MAE})},\ \text{R}^2 = 0.97 \tag{6}$$

where $\dot{m}$ is estimated grain flow rate (kg s^{-1}).

However, these equations also illustrate the challenge of estimating higher flow rates. Figure 6 shows that there are only small changes in the parameters at high flow rates (>5 kg s^{-1}), which may prevent estimation of high flow rates. The laser scanner could not measure high grain flow rates because the grain flow appears as a solid wall and does not allow the laser to penetrate the gaps in grain flow.

Table 1 shows the errors between the measured and predicted flow rates using equations 5 and 6 for different ranges of mass flow rate. The RMSE predicted grain flow rates up to 5 kg s^{-1} with very small error (max. 2.57%), but the error was high (>18%) for flow rates greater than 5 kg s^{-1}. The calculated errors for MAE were greater than those for RMSE but followed the same general trend. Thus, RMSE was the best estimator of mass flow rate in this study.

CONCLUSION

The results showed that grain flow could be detected using laser scanning for flow rates up to 5 kg s^{-1} using RMSE in an exponential model. The model error was less than 2.6% at mass flow rates less than 5 kg s^{-1}. The scanner used in this study was deflectable and does not require a sensor opposite the material stream. This is important because of the physical limitations for sensing equipment inside agricultural machines, especially combine harvesters. We believe it would be possible to detect and measure flow for other similar granular materials, but this requires additional testing to confirm.

REFERENCES

Abdul Rahim, R., & Green, R. G. (1998). Optical-fibre sensor for process tomography. *Control Eng. Practice, 6*(11), 1365-1371. http://dx.doi.org/10.1016/S0967-0661(98)00092-6.

Arslan, S., Inanc, F., Gray, J. N., & Colvin, T. S. (2000). Grain flow measurements with x-ray techniques. *Comput. Elec. Agric., 26*(1), 65-80. http://dx.doi.org/10.1016/S0168-1699(00)00074-0.

Grift, T. E., Walker, J. T., & Hofstee, J. W. (2001). Mass flow measurement of granular materials in aerial application: Part 2. Experimental model validation. *Trans. ASAE, 44*(1), 27-34. http://dx.doi.org/10.13031/2013.2300.

Jadhav, U. S. (2010). Volumetric yield monitoring system using laser scanner for citrus mechanical harvester. MS thesis. Gainesville, Fla.: University of Florida.

Lee, K. H., & Ehsani, R. (2008). Comparison of two 2D laser scanners for sensing object distances, shapes, and surface patterns. *Comput. Elec. Agric, 60*(2), 250-262. http://dx.doi.org/10.1016/j.compag.2007.08.007.

Liang, Z., Li, Y., Zhao, Z., & Yi, C. (2012). Monitoring method of separation loss in tangential-axial combine harvester. *Trans. Chinese Soc. Agric. Eng., 28*(2), 179-183. http://dx.doi.org/10.3969/j.issn.1002-6819.2012.z2.030.

Na, S. Y., Lee, W. S., Shin, D. J., Kim, J. Y., & Lee, B. (2005). Crop flow measurement using photosensors to reduce disturbance error in yield estimation. ASAE Paper No. 051131. St. Joseph, Mich.: ASAE. http://dx.doi.org/10.13031/2013.18869.

Table 1. Grain flow rate prediction errors.

		Grain Flow Rate (kg s^{-1})					
		$\dot{m}$ < 1	1 < $\dot{m}$ < 2	2 < $\dot{m}$ < 3	3 < $\dot{m}$ < 4	4 < $\dot{m}$ < 5	5 < $\dot{m}$
Average error (%)	RMSE	0.057	0.63	0.97	2.57	1.08	18.12
	MAE	5.17	15.42	9.09	5.7	6.68	31.41

Saeys, W., Lenaerts, B., Craessaerts, G., & De Baerdemaeker, J. (2009). Estimation of the crop density of small grains using LiDAR sensors. *Biosyst. Eng., 102*(1), 22-30. http://dx.doi.org/10.1016/j.biosystemseng.2008.10.003.
Shi, Y., Wang, N., Taylor, R. K., Raun, W. R., & Hardin, J. A. (2013). Automatic corn plant location and spacing measurement using laser line-scan technique. *Prec. Agric., 14*(5), 478-494. http://dx.doi.org/10.1007/s11119-013-9311-z.
Swisher, D. W., Borgelt, S. C., & Sudduth, K. A. (2000). Optical sensor for granular fertilizer flow rate measurement. *Trans. ASAE, 45*(4), 881-888. http://dx.doi.org/10.13031/2013.9935.
Zhao, Z., Li, Y., Chen, J., & Xu, J. (2011). Grain separation loss monitoring system in combine harvester. *Comput. Elec. Agric., 76*(2), 183-188. http://dx.doi.org/10.1016/j.compag.2011.01.016.