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An ASABE Meeting Presentation

Paper Number: 152189997

Measurement of Offloading Cylinder Pressure for Load Weight Determination in Peanut Yield Monitoring

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Written for presentation at the

2015 ASABE Annual International Meeting

Sponsored by ASABE

New Orleans, Louisiana

July 26 – 29, 2015

Abstract. *Several studies have been conducted in development of new sensor technologies and adaptation of existing sensor platforms for use in peanut yield monitoring. As compared to commercially available yield monitors for other crops, the systems tested for peanut yield monitoring have demonstrated less accuracy across an entire season. The simple and inexpensive technology developed and tested in this study allows for on-combine weight measurement of every load, which can be used to post-process correct mass flow data for peanut yield monitoring. Hydraulic pressure was measured by an analog pressure transducer throughout the dumping motion on the basket offloading cylinders of 69 loads on a 4-row Amadas 2108 peanut combine and 17 loads on a 6-row Amadas 2110 peanut combine. Basket angle was also measured at each measurement of hydraulic pressure using a rotary potentiometer mounted between the combine frames and the basket. Both systems demonstrated an average absolute load weight prediction error of less than 5.5% for large loads, with the greatest accuracy occurring at about 1/2 and 1/4 of the range of basket angular motion on the 2108 and 2110, respectively. In all models, load weight prediction error was highest at the beginning and ending ranges of basket travel. Knowledge of the general basket position where the greatest accuracy is achieved allows a limit or proximity switch to be included so that the hydraulic pressure is always measured at that specific basket angle. This technology addresses some of the current problems in peanut yield monitoring accuracy from using only a calibration from the first several loads of the season. Because this system provides a direct measure of load weight, it is unaffected by variables such as foreign material content, peanut moisture content, peanut pod size, and peanut types, that can produce considerable differences in on-the-go mass flow sensor responses.*

Keywords. *Yield monitor, peanut, hydraulic, weight measurement, precision agriculture.*

Introduction

Compared to other row crop harvesting operations, the peanut harvest utilizes a relatively low number of precision agriculture technologies. A great deal of research has been conducted in development of a yield monitor for peanut, although currently it is still not commercially available. To date, the only widely adopted precision agriculture technology to benefit the peanut harvest is RTK guidance for auto-steer, which has been demonstrated by Ortiz et al. (2013) to reduce peanut digging losses by minimizing row center deviation; increased net returns of 229 to 291 \$ ha^{-1} (566 to 719 \$ ac^{-1}) were reported for use of a guidance system centered over planting lines vs. use of a guidance center offset over planting lines by 180 mm (7.1 in). In the study presented here, a technology is developed and assessed for weighing peanut loads from combines. There are several reasons why a peanut harvesting operation would benefit from knowledge of weight of each combine load, including especially estimation of gross vehicle weights (GVWs) for transport equipment and for applications related to yield monitoring.

Agriculture producers regularly have to truck their crops from their farms to the buyer. To receive the greatest economic benefit from each trip to the buyer the producer must load the trucks with the greatest weight allowed by the Department of Transportation. The penalty for overloading includes fines and possible loss of material which must be unloaded (Snead, 1980). In short, the challenge is to load trucks as close to the allowable GVW limits as possible without exceeding those limits. If the producer exceeds the allowable GVW then their drivers could receive violations; on the other hand, if the grower is under the allowable GVW then this would present an opportunity cost and require that they make more trips to the buyer to get their product delivered. This in turn decreases the producer’s profit.

Knowledge of the weight of peanuts loaded to a trailer would be beneficial in addressing this challenge in GVW optimization. The same need was fulfilled in the earthmoving industry where loaded weight from an excavator or loader to a transport vehicle could be measured (Ehrich and Dobner, 1985; Snead, 1980). A less electronically sophisticated, but similar in principle system was developed for use in agriculture by Sheffield (1988). These inventions, similar to the system presented in this study, measured hydraulic pressure on the cylinder actuating a shovel or bucket at a specified angle and correlated that pressure to weight of the load. In addition to indicating GVWs for transport vehicles by accumulating bucket loads, Ehrich and Dobner explain that the system is also useful for evaluating and quantifying machine and operator productivity.

Another application of a basket weighing technology as applied to peanuts would be to use it to calibrate yield monitors, post-process correct data from them, or to evaluate calibration performance and drift over time; similar systems could likely be employed in basket-type cotton pickers. A basket weighing system could also be used independently from a yield monitor to quantify relative yield per region or per field. The same technology described here for peanut combines could also be employed on peanut dump carts or cotton boll buggies. There are commercially available weighing systems for dump carts that utilize load cell and strain gauge technologies at the wheel spindles and tongue for weighing the cart. However, these systems are expensive relative to the technology presented here, up to 10x the cost, and if they are installed aftermarket then some custom fabrication may be required to install the system components. Aside from installation of harnesses and a display monitor, installation of the system described below would only require mounting of a basket position switch and installation of a hydraulic tee fitted with a pressure transducer.

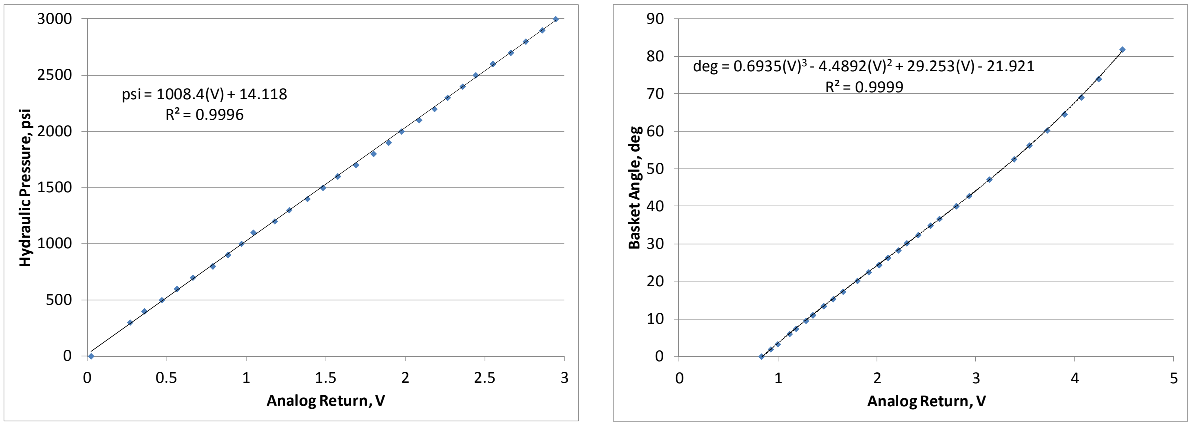
The objectives of this study were to: (1) design and develop a system using dump cylinder hydraulic pressure for estimation of load weight; (2) quantify load weight prediction error for such a system as installed on two combines; and (3) identify the best basket angles at which to make hydraulic pressure measurement, relative to accuracy of estimation.

Methods and Materials

The two combines used in this study were set up in the same manner, with the same components. A series TDH30 pressure transducer (Transducers Direct, Cincinnati, Ohio) was fitted on the hydraulic circuit of the offloading cylinders on 4-row Amadas 2108 and 6-row 2110 peanut combines (fig. 1a), indicating hydraulic pressure at the cap ends of the two parallel cylinders that tilt the basket for dumping the load to a wagon, trailer, or dump cart. The pressure transducers were calibrated against a model AFC-5M-25 pressure gauge (DiscountHydraulicHose.com, Philadelphia, Penn.) as shown in figure 2a using pressure generated from a model 60726 portable hydraulic power kit (Harbor Freight Tools Co., Camarillo, Calif.). Model AH226124 rotary potentiometer assemblies (Deere & Company, Moline, Ill.) were attached between the supporting frames and the baskets of the peanut combines (fig. 1b). The rotary potentiometers were calibrated against basket angle relative to the combines (fig. 2b) using a model 95998 magnetic digital angle gauge (Harbor Freight Tools Co., Camarillo, Calif.).

(a) (b)

Figure 1. Pressure transducer (a) and rotary potentiometer (b) as installed on 2108 peanut combine.



(a) (b)

Figure 2. Calibration of pressure transducer (a) and rotary potentiometer (b) for the 2108 combine. Calibration trends were similar for the 2110 combine. The lines on both plots indicate the linear regression functions applied, whose equations are indicated in overlays on the plots.

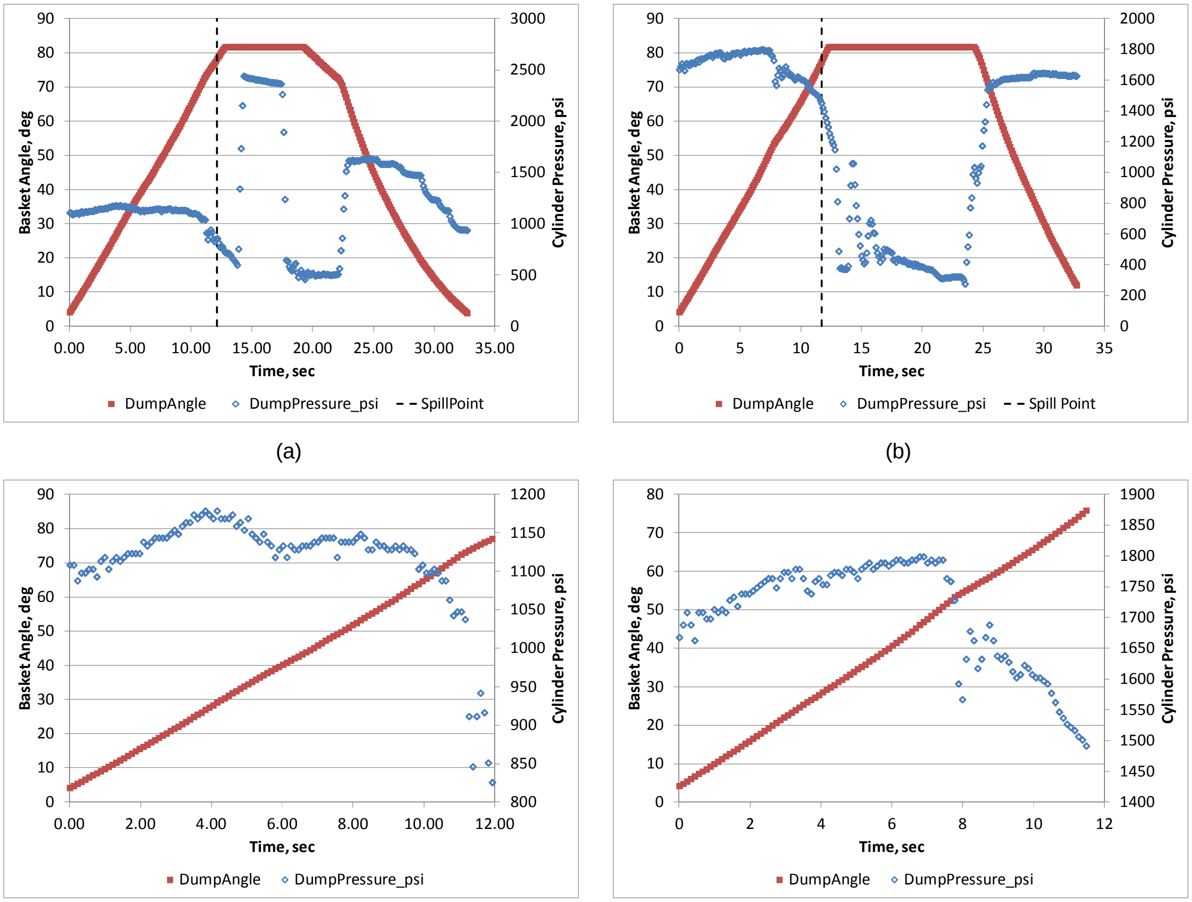
Sensor responses from the pressure transducers and rotary potentiometers were logged at 10 Hz with a custom data acquisition program written in Visual Basic 2010 Express (Microsoft Corp., Redmond, Wash.) using model 1018 interface kits (Phidgets Inc., Calgary, Alberta, Canada). Data acquisition for each dump cycle began after the basket angle exceeded a threshold of 4° and continued until the basket angle was once again below 4 degrees. The actual weight of each load was obtained using a Richardton dump cart (Sunflower Manufacturing, Beloit, Kans.) fitted with scales also running a custom data acquisition program written in Visual Basic 2010 Express, and using a model 1046 bridge board (Phidgets Inc., Calgary, Alberta, Canada). Stabilization of bridge data from the dump cart was provided by collecting bridge values at 4 Hz and reporting the average of 20 values.

The data from each dump cycle was trimmed to only include data on the lifting motion from 4° basket angle through 73° and 80° basket angle on the 2108 and 2110 combines, respectively, which generally represented a range beyond the spill point of the basket. Analysis of the trimmed hydraulic pressure and basket angle data from each dump cycle was conducted by averaging pressure data across each integer degree; the basket generally lifted at 6° sec^{-1} on the 2108 and 4° sec^{-1} on the 2110. This averaging allowed for analysis of the best angular positions at which to take hydraulic pressure readings, as discussed later. Single and multiple linear regression models were developed in Microsoft Excel (Microsoft Corp., Redmond, Wash.) to predict load weight as a function of dump cylinder pressure across a range of basket angles.

Testing for the dump cylinder pressure on the 2108 combine was conducted at Nix Farms, Bates Farms, and Clemson University Edisto Research and Education Center, all of which are located in Barnwell County, S.C. Testing on the 2110 combine was conducted on Joe Boddiford Farms located in Screven County, Ga. Data presented in this study was from 69 loads of runner and virginia type peanuts harvested with the 2108 combine and 17 loads of runner type peanuts harvested with the 2110 combine during the 2014 season.

Results and Discussion

The spill point or angle when peanuts generally began to fall from the basket, is represented in figure 3, showing representative data from two dump cycles of the 2108 combine. Data used for analysis was only that to the left of the spill point. It was noted on both combines that deceleration or reduction in hydraulic flow rate of the basket during the dump cycle (figs. 3b and 3d) resulted in brief periods of erratic pressure readings, as compared to maintenance of a relatively constant hydraulic flow rate (figs. 3a and 3c). At between 8 and 9 sec in figures 3b and 3d the hydraulic flow rate was reduced as indicated by the decreasing slope of the dump angle series resulting in instability of pressure readings; a similar phenomenon can be seen in figures 3a and 3c at between 11 and 12 sec. This observation is important to consider when designing an operating a system as described here because the fluctuations in pressure readings from deceleration of dump speed would increase load prediction error. It should be noted in figure 3a that the maximum angle indicated by the rotary potentiometer was less than the maximum angle that the basket would achieve, but greater than the spill point angle.



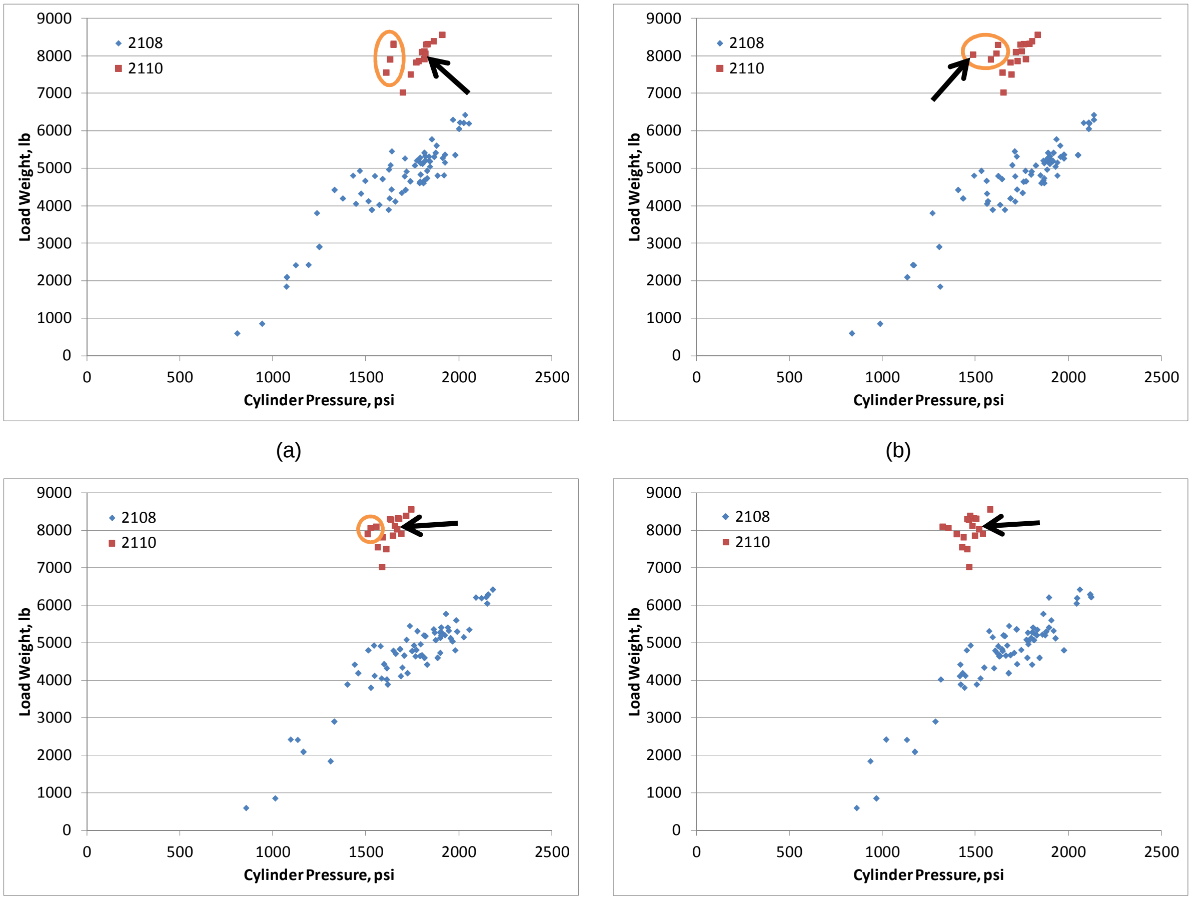
(a) (b)

(c) (d)

Figure 3. Basket angle and dump cylinder pressure as functions of time into dump cycle for two example loads on the 2108 combine. The entire dump cycle is represented in (a) and (b) and only the portion of the dump cycle below the spill point is represented in (c) and (d), which are trimmed from (a) and (b), respectively.

Regression models were developed to predict load weight as a function of dump cylinder pressure across loads at one degree increments of basket angle. For the 2108 combine, models were applied across “all loads” (n=69) and across “large loads” (n=62), which were taken to be those greater than 1,724 kg (3,800 lb). For the 2110 combine, only a “large loads” dataset was considered because all 17 loads were in excess of 3,178 kg (7,000 lb). The independent “large loads” analysis for the 2108 was conducted because practical application of this technology will likely most often be for large loads only. Models considered for each dataset were: linear, 2nd order polynomial, and 3rd order polynomial.

Figure 4 shows load weight for “all loads” on the 2108 combine as a function of dump cylinder pressure at basket angles of 15°, 30°, 45°, and 60° deg. As discussed, a rotary potentiometer was used during this study collect basket angle measurements, but could be replaced with a limit switch or proximity switch for commercial development since the full spectrum of the dump cycle would not necessarily need to be known. It is clear from the data that discontinuity in basket lift speed will affect load weight predictions. The points circled in orange for the 2110 dataset on figure 4 are points at which the angular velocity of the basket was inconsistent during the lifting motion. The arrow in each figure indicates the data point for load “P2_014”, where the basket lift speed was decelerated from 22° to 34°, as shown in figure 5 where basket lift speed was calculated as a ten point (1 sec) moving average. In figures 4a and 4c, at 15° and 45°, it can be seen that load “P2_014” follows the general trend for the other points that are not circled. In figure 4b, at 30°, which was within the range of deceleration, it can be seen that load “P2_014” does not follow the general trend of load weight as a function of pressure, as explained by the drop in pressure in figure 5 at 30°. As seen in figure 4d, there was little relationship between load weight and pressure for the 2110 at 60°. Analysis of the data suggests that the explanation for this is because the operator generally began to slow the lifting speed at and beyond this angle.



(a) (b)

(c) (d)

Figure 4. Load weight as a function of dump cylinder pressure on the 2108 and 2110 combine at basket angles of: 15° (a), 30° (b), 45° (c), and 60° (d). The points circled in orange for the 2110 indicate points at which basket lift speed was decelerated. The arrow for each plot indicates the data point for load “P2_014”, for which detail is shown in figure 5.

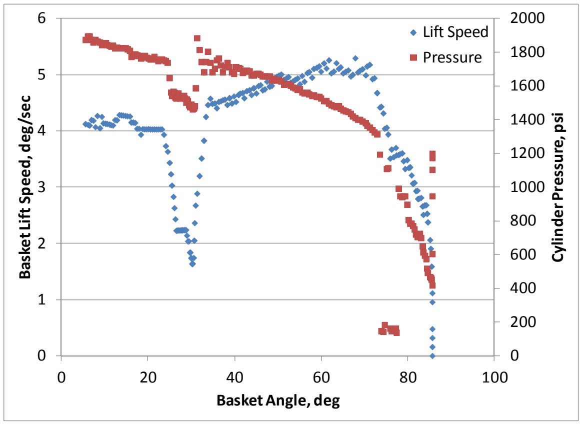
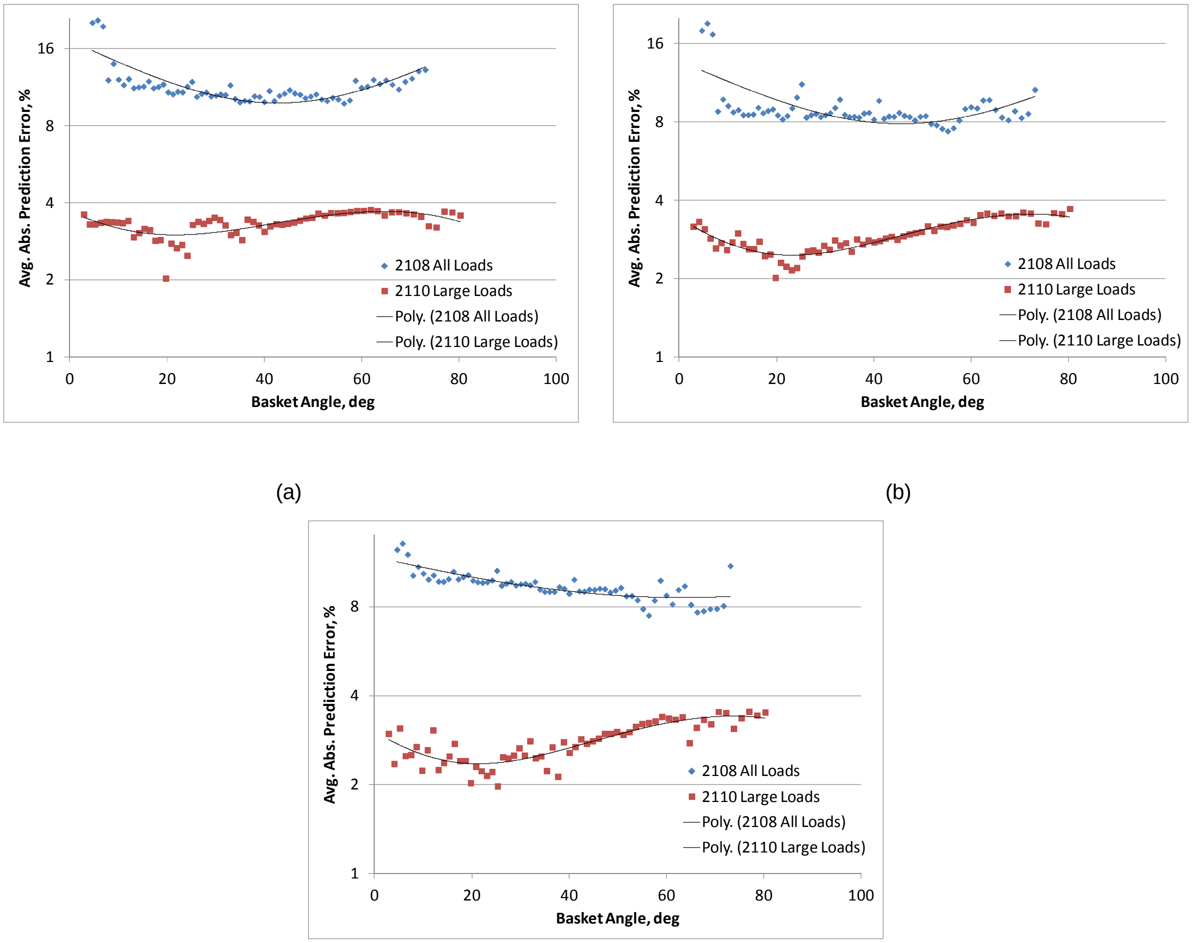


Figure 5. Basket lift speed and cylinder pressure as a function of basket angle for load "P2_014".

To determine the basket angles at which each load weight prediction model resulted in the greatest accuracy, prediction error for each model type was plotted as a function of basket angle, as seen in Figure 6. The errors reported in figure 6 are the average absolute load weight errors for the indicated regression model type applied at each angle. For each model type, figure 6 suggests the best basket position to place a limit or proximity switch. The first derivative of each equation for the polynomial trendlines shown in figure 6 were set equal to zero to determine the optimal basket angles reported here. A similar analysis, not graphically shown, was conducted for the 2108 "large loads" data set. As supported by the discussion accompanying figure 5, the optimal basket angle is likely not only a function of basket geometry, but also a function of the position(s) at which the operator is least likely to decelerate basket lift speed.



(a)

(b)

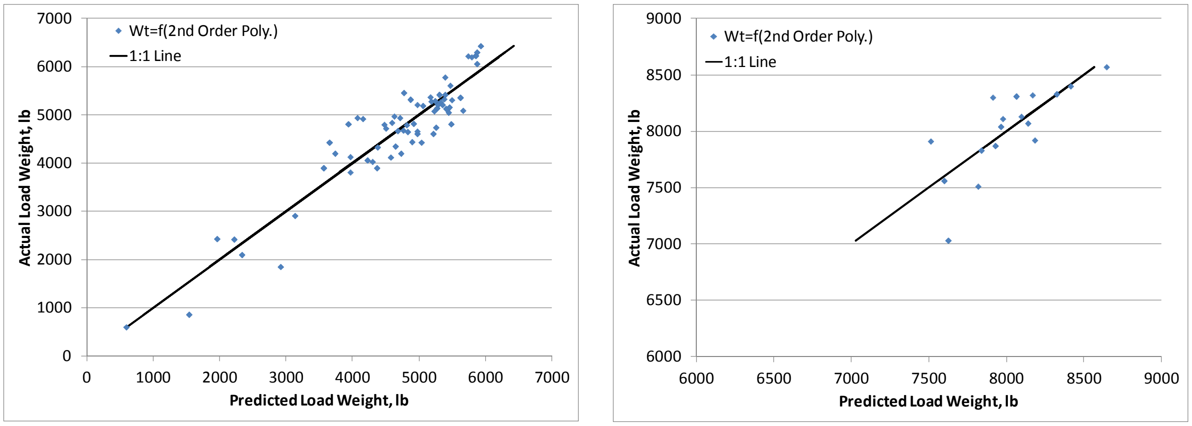
(c)

Figure 6. Average absolute load weight prediction error across all 2108 loads as a function of basket angle for: linear (a), 2nd order polynomial (b), and 3rd order polynomial (c) regression models. Solid lines represent 2nd and 3rd order polynomial trendlines to provide indication of angle at which least prediction error is observed.

A summary of the results from these analyses is provided in table 1 where the errors and coefficients of determination demonstrated are those for the model applied at the optimal suggested basket angle for the “all loads” and “large loads” datasets. For five out of six models on the 2108 combine, optimal basket angle was between 41° and 46°, or 50% and 56% of total basket angular travel. On the 2110 combine, optimal basket angle was between 22° and 23°, or about 25% of total basket angular travel for all three model types. In both datasets on the 2108 combine the second order polynomial model was numerically most accurate at 8.5% and 5.5% error for the “all loads” and “large loads” datasets, respectively. The second order polynomial model was also most accurate for the 2110 combine, tied with the third order polynomial model. As seen in figure 6c, the 3rd order polynomial model for the 2108 combine data demonstrates substantial variability in error at and near the optimal suggested basket angle; application of this model structure would therefore result in reduced confidence in load weight prediction. This degree of variability was not seen for a similar plot of the “large loads” dataset on the 2108 combine. Figure 7 shows actual load weight as a function of predicted load weight for the 2108 “all loads” (fig. 7a) and 2110 “large loads” (fig. 7b) datasets using 2nd order polynomial regressions at the optimal basket angles as indicated in table 1.

Table 1. Demonstration of optimal basket angle, and model error and coefficients of variation for model application at the optimal basket angle within each dataset.

		2108 Combine			2110 Combine		
Dataset	Model Type	Optimum Angle, °	Avg. Abs. Error, %	R^2	Optimum Angle, °	Avg. Abs. Error, %	R^2
All Loads	Linear	43	10.5	0.92	-	-	-
	2nd Order Poly.	46	8.5	0.87	-	-	-
	3rd Order Poly.	64	9.4	0.87	-	-	-
Large Loads	Linear	46	5.9	0.68	22	2.7	0.46
	2nd Order Poly.	43	5.5	0.73	23	2.2	0.60
	3rd Order Poly.	41	5.7	0.72	22	2.2	0.60



(a) (b)

Figure 7. Actual load weight as a function of predicted load weight using 2nd order polynomial models at optimal basket angles for: (a) 2108 “all loads” and (b) 2110 “large loads” datasets.

More data, especially across a wider range of load weights must be collected on the 2110 combine to fully characterize its load weight prediction error. It is expected that load weight prediction error could be improved by slope, or pitch and roll, compensation from a gyrometer, and hydraulic fluid temperature compensation. Although it may be negligible in this application, fluid temperature will have some effect on indicated hydraulic pressure; temperature compensation for hydraulic load cells was employed as early as 1965 (Bradley). Because the force required by the hydraulic cylinders to tilt the basket is a function of the position of the center of gravity of the basket, slope will also have some effect on load weight prediction error, likely a greater effect on roll than pitch for side dump peanut combines. Correction for slope was stated to be unnecessary at typically experienced slopes in the peanut yield monitoring system described by Vellidis et al. (2001) where the basket was supported by four load cells. A study by Fulton et al. (2008) indicated that a grain mass flow sensor would benefit from slope compensation, but that pitch was more important than roll because of the effects of gravity relative to sensor position. A clever method for compensating for slope on a load cell based hay bale weighing system corrects the bale weight as a function of the empty baler weight on the slope, as compared to that on flat ground (Kraus, 2014); such a system might be employable here as well.

Conclusion

The results from this study show that predicting peanut load weight based on hydraulic pressure at the basket lifting cylinders is possible and would be fairly simple to retrofit onto machines. Such a system would require incorporation of a switch and a pressure transducer, the switch being used to trigger the pressure measurement at the same basket position for each dump cycle. The switch should be positioned to minimize errors in load weight prediction, although the data from this study suggests that the optimum basket angle may differ from machine to machine, with optimal suggested angles of 43° and 22° on the 2108 and 2110 combines in this study, respectively. Slowing of the basket speed by reducing hydraulic flow rate delivered to the cylinders was found to have a profound negative effect on load weight prediction. Therefore, optimum basket angle is also affected by the operator’s control habits; basket positions at which the operator regularly slows the basket lifting speed are poor positions to choose for pressure indication.

Load weight prediction error was demonstrated to be less than 9% across all load weights on the 2108 combine and less than 6% and 3% across large load weights on the 2108 and 2110 combines, respectively. Some of this error is attributed inconsistencies in basket lift speed across loads and it is expected that additional error could be explained by machine slope and fluid temperature. Future work is already planned to evaluate these corrections, in addition to evaluation of the system on platforms other than peanut combines. The same concepts discussed and presented here for a peanut combine are applicable and relevant to any loads that are hydraulically lifted or dumped, for example in peanut dump carts, cotton pickers, and cotton boll buggies, and the technology employed is as low as one tenth of the price of load cell based systems.

Acknowledgments

Thank you to the Clemson University Research Foundation (CURF) for providing funding for this project through the Technology Maturation Fund. Thank you to Joe and Knapp Boddiford of Joe Boddiford Farms (Sylvania, Ga.), Rob Bates Farms (Blackville, S.C.), and Walker Nix Farms (Blackville, S.C.) for your cooperation in data collection and harvesting. Thanks also goes to Amadas Industries, for making available the 2108 combine used in this study and once again to Joe Boddiford Farms for making available the 2110 combine used in this study.

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