Crop flow measurement using photosensors to reduce disturbance errors in yield estimation

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Abstract. It would be desirable to produce a precision yield map using smaller area for mass measurements. However, when the reaping distance decreases for each measurement, disturbance effects become prominent. Since tractors or trailers have rather larger masses compared to harvested crop mass, disturbance effects of ground undulation through the vehicle dynamics overwhelm the harvested mass of a unit area. Therefore, it is inevitable to provide a method to remove the error components from the yield data.

In this study, an indirect method of crop flow measurement is suggested to show robustness to the disturbance. The proposed method is counting the number of interrupted light transmission in arrays of LED and phototransistor sets, and then mass data can be obtained through a predetermined relationship between crop flow and photosensor output. Since the number of interrupted light transmission is counted without any contact, vehicle vibration has no effects on the measurements.

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The experiments were conducted for the small scale flows of beans, rice, and bamboo strips under extreme vibration. Converted mass from the photosensor output show no effects on vibration, even though the mass obtained by load cells have much greater magnitudes of noises than the mass itself.

Keywords. Disturbance reduction, photosensor, precision agriculture, yield estimation
Introduction

One of the most essential tasks in yield monitoring systems is accurately measuring mass or volume of crop flow. Although many yield monitoring systems have been developed and commercialized for different crops, error reduction and calibration routines have been considered to be improved further. Reduction of error in yield data from harvesting operations was addressed with several error sources (Blackmore and Marshall, 1996).

This paper explores a possibility of reducing noise in mass flow signal due to the vertical movement of trailers using photosensors. A signal processing method was proposed in this paper to reduce dynamic mass errors for a trailer-based yield mapping. Essentially weighing problem is dynamic since crop mass is changing during harvesting operation in addition to the effects of ground undulation or vehicle vibration. The overall goal of this research is to explore feasibility of using photosensors to reduce noise in yield estimation. The specific objectives of this paper were:

- to design and build an experimental model yield estimating system,
- to implement a photo-sensing technique for measuring crop flow, and
- to compare the proposed method with conventional methods based on load cells in terms of noise reduction in the experimental yield monitoring system.

Recently there has been much effort to develop yield monitor performance standards by the ASAE Precision Agriculture Committee, PM-54, to "provide the basic requirements for a uniform procedure to measure and report yield monitor accuracy". At the time of this publication, the standards were divided into two standards, i.e., X578 Yield monitor performance test standard, and X579 Yield monitor field test engineering procedure. Even though those standards define various aspects of testing procedures, this paper focuses only on the possibility of utilizing photo-sensing techniques to reduce errors in a yield monitoring system.

Background

Many approaches have been developed for dynamic weighing in a fast and accurate way for various applications. For ideal step cases such as using an adaptive filtering method (Shu, 1993) and a nonlinear regression technique (Danaci and Horrocks, 1995) were fundamental approaches. Also an artificial neural network was used to obtain necessary parameters of weighing system models to estimate dynamic weights (Bahar and Horrocks, 1998). Various parameters associated in a complex system could be optimized adaptively using genetic algorithms in an evolution-based design (Alpaydin et al., 2002). However, yield monitoring requires dynamic on-the-go weighing in harsh conditions. There are complex influences during harvesting operation from tractors and trailers, and ground undulation that tend to deviate from their models.

There are a lot of computational burden as well as complexity to cope with many parameters of the models of the external effects. An extra load cell and a reference mass were installed to compute indirect reference acceleration to avoid this difficulty (van Bergeijk et al., 1997; Krumpelman and Sudduth, 2000). In addition to low-pass filtering and moving average, the calculated acceleration data were used to get rid of error components due to vibration and disturbances. Without any reference mass nor extra load cell, direct measurement of vertical acceleration by a MEMS type accelerometer could be used to cancel out noise components that are common to load cell data and acceleration data (Na, et al., 2003).
Over the past two decades there have been growing interests and applications for the use of multiple sensors (Luo and Kay, 1995) to increase intelligence and robustness of various machines and systems (Martel and Savoie, 2000). Integrating information provided by multiple sensors into the operation of a system is the synergistic use of individual sensor functions in the forms of sensor-data integration and fusion (McDaniel, et al., 1998).

Array of light sources and photosensors are frequently used to measure grain volume within a clean grain system for yield monitoring (Morgan and Ess, 2003). It detects the degree to which a bin is loaded. One of the most distinguishing features of the photosensors is the immunity to vibration or shock disturbance compared to the other types of mass or volume measuring sensors such as load cells, position transducers and/or impact force sensors. Sui et al. (2004) has implemented an optical sensors to measure cotton flow in a cotton picker duct and reported that the cotton yield monitor’s average absolute error was 3.8% after the system has been tested on 42 different loads.

Materials and methods

**Experimental apparatus for measurement of mass and volume of crop flow**

A small-scale model weighing system (Figure 1) was designed and used to acquire mass and acceleration data. Four 10 kg compact tension/compression load cells (model: UU, Dacell (www.danaloadcell.com)) of strain gauge type for general purposes were installed on the four corners of the top of the base. The load cells’ rated output was 2.0 mV/V and the error rate was 0.03%. The maximum output was 6.6 mV for a common 3.3 V operating voltage. To measure the vibration of the bin which affected the load cell readings, an accelerometer (model: ADXL202, Analog Devices) was installed at the center of the bottom of the bin (Na, et al., 2003). It was a 14-pin chip containing a MEMS type sensor inside, measuring acceleration in the range of ±2 G. The same 3.3 V operating voltage was applied to produce an output voltage of 0.0 V for −2 G, 3.3/2 V for 0 G, and 3.3 V for 2 G.

![Figure 1](image1.png)

**Figure 1.** Experimental model weighing system made of 8-mm thick acrylic plates. Compact tension/compression load cells were installed on four corners.

![Figure 2](image2.png)

**Figure 2.** Hopper for measuring grain flow.
**Photosensor module**

Arrays of light sources and photosensors have been frequently used to measure grain volume within a clean grain system for yield monitoring (Morgan and Ess, 1997). They detect light and dark periods by the blockage of the grain flow between the light source and the corresponding photo transistors. Photosensor information during a certain period of time can be converted to mass of the grain during the same time interval. Since photosensors are immune to vibration or shock disturbance compared to load cells, photosensor information could be used to reduce disturbance errors due to vibration for the dynamic mass measurement in this research.

As in Figure 3, three arrays of eight photosensors were devised, and installed at the outlet through which grains flowed to measuring bin. Photo transistors were ST-310 models and photo diodes were infrared (IR) light emitting diodes from Kodenshi (G-310).

![Figure 3. Photosensors (photo diode array and photo transistor array) and three arrays.](image)

Photosensor arrays were directly interfaced with the microprocessor (MSP430F149) using DIO (digital input/output) ports. Photosensor outputs were sampled at 250 Hz which was the same sampling rate for load cells and the acceleration sensor as well.

![Figure 4. Installation of photosensors in the experimental hopper.](image)

Figure 5 shows the installation of the three arrays of photosensors at the outlet of the hopper. The LED had a radiation angle of ±5°, thus a slit panel was used between the photo diode arrays and photo transistor arrays. The panel had holes exactly at the same positions of the photo diodes so that one photo diode could correspond only to one photo transistor at the same matching position. The photosensor module was covered with black paper to make the effect of natural sunlight as small as possible during tests on the coarse surface ground.
Data acquisition system

A data acquisition system based on a 16-bit microprocessor (model: MSP430F149, Texas Instruments) was designed to process data from the three arrays of photosensors, four load cells, a temperature sensor (model: LM35, National Semiconductor), and an accelerometer. The MSP430F149 microprocessor operated by a single 3.3 V source had 8 channels of 12-bit A/D converters, two 16-bit timers, and two USART (universal serial synchronous/asynchronous communication interfaces) ports. Sampling frequency was 250 Hz. Each channel was sampled at 2 µs in sequence and then each data set was processed and sent to a host PC through a serial port.

Materials for flow tests

For the flow test procedure, dried brown and yellow soybeans, rice, and bamboo chips were selected as simulated crops. Brown and yellow soybeans had similar size and shape each other, but their colors were different which might cause reflection difference.

The size of rice was smaller than the space between the photosensors of the arrays. The length of bamboo chips was selected to be detected by multiple sensors. An SUV containing the hopper and the weighing bin was operated on an unpaved coarse-surface ground at 20 km/h, while the mass and photosensor data were recorded by the data acquisition system.
Results and discussion

Frequency domain analysis

Power spectrum densities (PSDs) of load cells and acceleration data were analyzed to investigate effects of vehicle vibration and ground undulation on the crop mass measurement system on the SUV while moving. A typical PSD during operation is shown in Figures 7. Based upon the PSD curves, it was assumed that frequency components of the PSD less than 4 Hz corresponded to the effects of ground undulation, and the components between 4 to 10 Hz were due to small scale objects between tires and ground. There were harmonics components of 22.7 Hz due to vehicle characteristics as well.

![Figure 7. PSD of load cell output while moving at 20 km/h.](image)

Reference ratio between mass change and photosensor outputs

Reference ratios between constant mass increase and the photosensor outputs were obtained through experiments under the condition with no disturbance. Several flow rates with different opening size of the hopper exit were tried. Figure 8 shows the conversion ratios for the materials of brown and yellow soybeans, rice, and bamboo chips. These ratios were taken as references when measurements were made while disturbance signals were added.

(a) black soybean  
(b) yellow soybean
Figure 8. Mass measured by load cell and photosensors for four different materials.

The correlation coefficients in Table 1 were obtained between the mass converted from photosensors and the mass from load cells. The mass from load cells were smoothed by conventional low-pass filtering and moving average methods. The correlation coefficients calculated using Matlab (corrcoef.m) are very close to one.

<table>
<thead>
<tr>
<th>C.C. materials</th>
<th>Low-pass filtered mass</th>
<th>moving averaged mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>black soybean</td>
<td>0.9976</td>
<td>0.9978</td>
</tr>
<tr>
<td>yellow soybean</td>
<td>0.9987</td>
<td>0.9988</td>
</tr>
<tr>
<td>rice</td>
<td>0.9996</td>
<td>0.9996</td>
</tr>
<tr>
<td>bamboo chips</td>
<td>0.9922</td>
<td>0.9942</td>
</tr>
</tbody>
</table>

The ratios depended on the types of crops, shapes of the grains, and the moisture content of the flow. Also, the surface of the arrays had to be maintained clean so that there were no accumulated residues on the surfaces which could cause continuous blockage. Sampling time of photosensors was 4 ms.

Since speed of grain flow depended on grain shape, density, moisture contents, etc., the OR operations of previous photosensor data were used to obtain the best linearity ratio of the flow and the mass increase. It was 24 for soybean samples.

Another parameter to be considered was the delay time between the photo detection and the load cell measurements. It was found experimentally that the delay was 400 ms (100 sampling times).

Raw mass data by load cells were processed by a low pass filter which had 4Hz cutoff frequency, and also smoothed by moving average of 300 points. Figures 9 – 12 show the results for the four types of flow materials.
Figure 9. Mass measured by the load cells and photosensors for black soybeans.

Figure 10. Mass measured by the load cells and photosensors for yellow soybeans.
Figure 11. Mass measured by the load cells and photosensors for rice.

Figure 12. Mass measured by the load cells and photosensors for bamboo chips.
The detailed portions of Figures 9 – 12 are shown in Figure 13 to make the comparison between the three results, i.e., low pass filtered mass, moving averaged mass, and mass estimated by photosensors. Although the true values of mass were not known, they were assumed to be increasing with little fluctuation since the opening of the hopper exit was kept constant. This fact was indirectly evident, since the correlation coefficients were nearly one for the static operation. In real mass measurements during simulated crop operations, there were much noise components added. Figure 13 shows the converted mass data from photosensor arrays were better than those of conventional processing from load cell measurements.

Field testing of the photosensor system

A similar mass flow measurement system by arrays of photosensors (Figure 14) was designed and installed on a two-row silage chopper (Hesston 7165, Hesston Corp., Hesston, KS). The system was tested during sorghum harvesting in November, 2004 at the Plant Science Research and Education Unit of the University of Florida located in Citra, FL. A total of nine loads of silage sorghum was harvested and used for testing the system. Accumulated mass measured by load cells, acceleration, photosensor, and location information were recorded during the harvesting operation. The relationship between silage mass flow and the photosensor output is being investigated.

Due to variation of moisture contents of crop flow, crop residues on the surfaces of the photosensor module, and irregularity of crop sizes may cause the results deteriorate compared to those of small-scale simulation. It will be necessary to develop supporting techniques such as wiping out residues periodically on the photosensor module.
Conclusions

A mass flow measurement derived from a photosensor output was proposed to reduce dynamic mass errors for a trailer-based yield estimating system. Small scale experiments were conducted using a van driving at 20 km/h on an unpaved coarse-surface ground. Field tests were conducted using a photosensor installed on a silage harvester for sorghum harvesting.

- The mass measurement data by the proposed photosensor arrays were better in terms of immunity to dynamic disturbance errors compared to the conventional mass measurements by load cells.
- The correlation coefficients between photosensor derived mass and low-pass filtered mass were found to be very close to one (0.9922-0.9996) for four different materials (black soybean, yellow soybean, rice, and bamboo chips) during flow measurement testing.

References


