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In-situ non-linear calibration of grain-yield sensor*

— Optimization of parameters for flow rate of grain vs. force on the sensor —

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Abstract

In-situ calibration of a mini-yield sensor (mounted on a five-row grain combine) with a non-linear relation to the flow rate was examined. Instead of measuring or controlling the flow rate of grain for calibration purposes, 10 or 12 pairs of grain weights and signal recordings were collected directly in the fields; three such data sets (weights and signals) were obtained. Two parameters of the relation were optimized so as to minimize the standard error. The relative error of validation was 3% to 5% with data sets of a wide range of flow rates, whereas it was up to nearly 10% with a data set of low flow rates. The optimized parameters varied with each data set, but those yielding low errors were common in the response surface of error, regardless of the data sets.

[Keywords] Grain weight, flow rate, standard error, response surface, cross-validation

I Introduction

Calibration of grain-yield sensors is requisite for ensuring their accuracy for specific varieties of crops and under specific operating conditions of combines. Efforts have therefore been made to fabricate reliable testing stands for calibration. Arslan and Colvin (1998) have constructed a testing stand with an electronic scale to verify yield sensors with the weight of accumulated grain, and have conducted indoor experiments by changing the flow rate of grain (Arslan and Colvin, 1999). Burks *et al.* (2003, 2004) have constructed indoor weighing and metering devices for grain and have conducted similar experiments. Al-Mahasneh and Colvin (2000) have mounted an electronic scale on a combine, and Arslan and Colvin (2002) have therewith then conducted field experiments. Loghavi *et al.* (2008) have developed a portable testing stand that controls the flow rate of grain, so that the sensors can be calibrated directly on the combine where they are mounted. Their main focus was to observe the performance of the yield monitor under various flow rates, sudden changes (step response), and under various inclinations of the combine, specifically in terms of elapsed time. They have not, however, directly shown the relation between flow rate of grain and output of sensors.

If a linear relation is assumed such that:

$$q = kF \,, \tag{1}$$

then by taking the integral form of Eq. (1) with time, the calibration can be as simple as the following:

$$w = \int q dt = k \int F dt \tag{2}$$

where q is the flow rate of grain, F the output of the sensor, k a parameter to be calibrated, and w the weight of the accumulated grain. Equation (2) shows that only continuous recordings of the output and the weights of the accumulated grain are needed for the linear calibration.

This linear relation is, however, limited to a specific combine (Shoji *et al.,* 2009). The output of the sensor is generally non-linear to the flow rate (Schrock *et al.*, 1999); very low output is usually observed under low flow rates and vice versa. A similar procedure with Eq. (2) is no longer valid and, therefore, devices and innovation are needed for precise control of the flow rate of grain, as reviewed above, in order to carry out reliable calibrations.

The present paper proposes an alternative and simple method of calibrating grain-yield sensors with a potentially non-linear relation, specifically, by using only several pairs of recording of the output and the weight of the accumulated grain, similar to those we have suggested for linear sensors (Shoji *et al.,* 2009). Without relying on devices controlling the flow rate of grain, combine operators will be able to easily calibrate the sensor-combine system in the field according to the varieties or the conditions of the crop grown.

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II Materials and Methods

1. Yield sensor and signal processing

The sensor consists of a ring load cell and an impact plate (Fig. 1), totaling only 0.021 kg, as described by Shoji *et al.* (2009). The reduced mass is intended to minimize the influence of external vibration on the output of the sensor.

The output of the sensor is amplified and processed through a low-pass filter (cut-off frequency of 200 Hz) and recorded at a sampling rate of 1 kHz into a compact flash card. In offline processing, one-second average of the output is calculated and stored in another file, with the instantaneous zero-point of the output being updated every one second (self-compensation for zero-point) as proposed by Shoji *et al.* (*in press*); signals with absolute value exceeding a threshold of F_{th} are regarded as impact, and other signals are averaged to calculate the instantaneous zero-point.

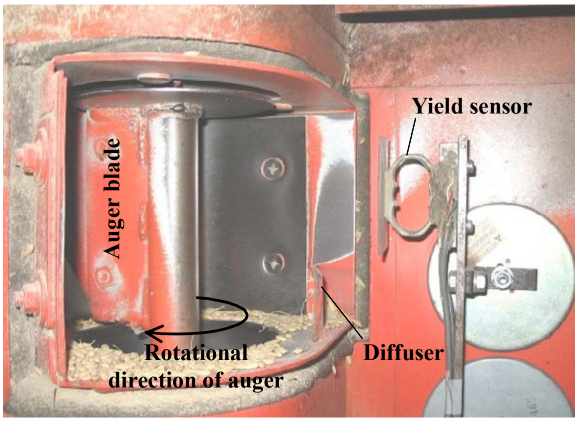

Fig. 1 The yield sensor mounted on the combine inside the grain tank.

Fig. 2 The five-row *jidatsu* combine in operation.

2. Combines and experiments

The sensor was mounted inside the grain tank of a 5-row *jidatsu* grain combine (KUBOTA, R1-551, Fig. 2) near the upper exit of the vertical grain auger to receive a portion of the grain accelerated by the auger blade (Fig. 1).

Stationary trials were conducted by changing the flow rate of dry grain (13.5% w.b.) being poured directly into the grain pan of the combine. Five kilograms of grain were poured manually at as constant a rate as possible, and the average flow rate calculated by dividing the weight by the duration of pouring ranged between 0.19 and 1.85 kg/s. The average force on the sensor was calculated without the self-compensation and compared with the average flow rate. The purpose of this preliminary experiment was to find a rough relation between the average force and the flow rate, for possible use as a model for calibration in field experiments.

Field experiments were conducted in two seasons (2005 and 2007, Table 1) at the Food-Resource Education and Research Center of Kobe University (Kasai City, Hyogo, Japan). Portions of 0.5-ha paddy fields (*Oryza sativa L.*, cultivars: *Hinohikari*) were harvested with the combine. Each recording of signals was continued until the grain was unloaded from the grain tank (every 2 or 4 paths), and the total amount of grain was weighed manually. The flow rate of the grain was varied mainly by changing the operating speed of the combine. The cutting width of the combine was either 4 or 5 rows (1.2 or 1.5 m). A total of three data sets consisting of 10 or 12 pairs (weights and recordings) were obtained.

Table 1 Summary of the field experiments

Data set	2005-1	2005-2	2007
Moisture content of grain (%)	20.2±0.8	20.2±1.2	21.6±0.8
Average operating speed* (m/s)	0.37~1.45	0.31~0.62	0.38~1.60
Average flow rate of grain* (kg/s)	0.23~0.99	0.34~0.58	0.35~1.01
Total grain weight (kg)	1825	1950	1878
Pair of data (weight and recording)	10	10	12

* Traveled distance or grain weight divided by actual operating time

III Results and Discussion

1. Rough relation between flow rate and average force

Unlike the linear relation reported for a two-row combine (Shoji *et al., in press*), the stationary trial, here, showed that the average force on the sensor was not proportional to the flow rate of grain (Fig. 3); the output was very low at a low flow rate, as reported by Loghavi *et al.* (2008) and Schrock *et al.* (1999). Not only the incidence of the impacts, but also the amplitude of the impacts was affected by the flow rate (Fig. 4). One of the possible reasons for this non-linearity is that the diffuser near the auger blade hindered the grain flow to the sensor. At a low flow rate, a considerable portion of grain may have escaped from the open space around the auger blade (Fig. 1).