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Application of fibre sensor in grain drill to estimate seed flow under field operational conditions

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ABSTRACT

A new sensing system to estimate the mass flow of seeds in the grain drill was developed and evaluated in this paper. This was a manipulation of an estimation model developed indoors using fibre sensors; by considering the operational conditions of the machine and environment. Therefore, an original method to install the sensor within the grain drill was tried, and modifications on the estimation model and algorithm were performed.

The experiment to test and evaluate the sensing system consisted of running a grain drill-propelling tractor in the farm of Hokkaido University several times to sow rye seeds, where each run was approximately 160 m. Two fibre sensors were installed at two different metering units, that use axial flute rollers, inside the grain drill. Also, the seeds being discharged during the experiment were collected and weighed at the end of each run. The results of 52 trials to estimate the mass flow of seeds indicated that in approximately 98% of the trials the estimation rate exceeded 90%. Moreover, the overall estimation rate was approximately 95%. These results seemed not to be biased by the change of the sensor set nor the sensing location.

The modifications on the estimation model were successful in eliminating the overestimation or underestimation bias that resulted by changing the speed in the indoor experiments. In addition, the modifications on the estimation algorithm could eliminate error in the sensor output values that may result from dust, vibration, or variation in the sensor internal resistance. These results showed that the sensing system can be used practically to monitor the seed flow in the grain drill which would have many applications in precision agriculture practices.

1. Introduction

The grain drill is a tractor propelled vehicle used primarily to sow grain seeds. Sowing differs from seeding in that; while seeding aims to place seeds one by one at a certain spatial interval, sowing aims to cover the farm by a uniform distribution of seeds. Therefore, unlike seeders, which have multiple small hoppers placing seeds in relatively far distances, grain drills have one big hopper with many outlet pipes close to each other so as to ensure the maximum possible coverage of the ground.

Power in the grain drill is required to rotate internal shafts. One of these shafts carries sowing metering flute rollers which deliver seeds to the outlet pipes. In order to optimize the application of the grain drill, the width of the rollers may be adjusted manually. This is one of the measures that allow using the drill to sow different variety of seeds classified according to their sizes.

The performance of the grain drill is evaluated according to the uniformity in distributing seeds throughout the sowing operation. Since all shafts are connected to the tyre of the grain drill, the increase of the forward speed of the grain drill will cause a faster rate of sowing by the rollers. This will ensure a theoretical uniformity of sowing throughout the land regardless of the forward speed. Nevertheless, Maleki et al. (2006) reported that seed uniformity using fluted-rollers is still impaired due to sudden releases of seed batches and suggested modifications on the design of the rollers to improve uniformity.

Therefore, the recent years have witnessed some new approaches to develop more controlled sowing metering systems. One of these approaches is based on using pneumatic device to improve the precision of the metering system in releasing grains, as designed and tested by Yasir et al. (2012). Another approach is based on a more radical modification on the conventional metering system. It suggests replacing the chain mechanism that transmits power from the rotation of the tyres to the flute roller shaft, by an electronic system that synchronizes the rotational speeds of

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Nomenclature

N	natural number {1, 2, 3, ...}	d	density of clump during one period of time
L	length of clump during one period of time	m	mass of clumps during one period of time
V	value of voltage output during the experiment	β_i	coefficient of the i-th variable
a	initial value of voltage output		

the tyres and the shaft, as developed and tested by Zhai et al. (2014), as well as Kamgar et al. (2015). The latter approach aims mainly to overcome the problem of slippage that occur while sowing.

Despite these advancements in trying to improve the performance of the grain drill, a full system that provides a feedback from the seeds about their flow is yet to be tackled. Currently, a rough evaluation of the flow may be drawn based on yield at the end of the season; by analyzing the amount and distribution of the yield in comparison with past seasons. Nevertheless, there are several factors that might affect the yield during the growing season, beside seed distribution, and decisions about sowing can hardly be taken without further considerations, as shown by De Bruin and Pedersen's study on soybeans (2008), as well as Weisz and Heiniger's study on small grain seeds (2012).

Additionally, in the current sowing practices using grain drills, the operator must periodically monitor the amount of seeds in the hopper so as to avoid running out of seeds while the grain drill is operating. Since there does not exist any way to neither accurately estimate the input of seeds to the hopper nor having information about the sowing operation itself, the operator will be forced to fill the hopper more frequently than he or she should. This means that the efficiency of the operation would become much lower than it could be; if the operator were to have a feedback about the sowing operation and the seed distribution.

In order to equip the grain drill with a feedback mechanism of its operation, it is necessary to develop a sensing system which can estimate the flow rate of grain seeds under the operational conditions. Traditionally, most of the research efforts to develop seed sensing systems were concentrated on seeding mechanisms rather than sowing because of the high cost of bigger seeds, such as beans, and the vital effect of distance between seeds on the yield. Some of these researches used opto-electronic sensors (Kocher et al., 1998; Lan et al., 1999), high speed cameras (Karayel et al., 2006; Zhan et al., 2010), or infrared sensor equipped with an embedded system (Okopnik and Falate, 2014). On the other hand, trials to develop sensing system for small seeds in the grain drill have been scarce until recently.

Earlier, the authors developed a model to estimate the mass flow of small seeds using a fibre sensor (Al-Mallahi and Kataoka, 2013). Similarly, Raheman and Kumar (2015) used an infrared sensor equipped with and embedded system to detect the seed flow. The difficulty in developing a sensing system of the flow of small seeds in a grain drill has been that the seeds flow in clumps. While the latter research work was able to detect the passage of the clumps at different flow rates, the former work was able to go a further step of estimating the mass of each clump by manipulating the sensor data statistically and developing a mass estimation model. However, all trials to develop such systems have been developed based on indoor experiments. Therefore, there has been a need to test these systems outdoors, so as to adapt any sensing system developed indoors to the outdoor operational conditions where environmental effects may be uncontrolled.

Consequently, the objective of this research work was to adapt the sensing system developed by the authors to outdoor operational conditions. This could be achieved by installing the sensors on the grain drill, and modifying the mass estimation model and its governing algorithm to the outdoor operational conditions including, machine vibration, dust, and different tractor running speeds. Accordingly, a grain drill was set up, firstly, to run an experiment of sowing rye seeds by installing two sets of optical fibre sensors. Next, the ability of the sensing system to estimate the mass flow was assessed. This was achieved by comparing actual mass of seeds collected during the experiment with the mass estimated after considering all the operational impacts on the estimation model and algorithm.

2. Materials and methods

2.1. Grain drill

The grain drill used to conduct the outdoor experiment was Tume (KL, 2500). Fig. 1 shows a back view of the grain drill. It is designed to apply fertilizers simultaneously while sowing. Therefore, the hopper is divided, in fact, into a front and back hoppers that contain fertilizers and seeds, respectively. The width of the drill is 2.5 m, through which the seeds and fertilizers are discharged downwards using an axial flute roller system. There are 20 and 12 metering units in the seed and fertilizer hoppers, respectively.

Each metering unit consists of a shutter, the flute roller, and a spring loaded bottom valve as described by the sketch of Fig. 2, which is a simplification of the metering unit description in the datasheet of the drill manufacturer (Tume-agri, n.d). The shutter may separate the metering unit from the hopper, while the inclination of the bottom valve determines the amount of seeds that can be pushed off by the flutes of the roller. The pushed seeds form clumps that flow through a funnel towards outlet pipes that lead these clumps towards the designated locations in the soil. The frame, on which all outlet pipes are arranged, is hooked to the frame of the hopper by a trough; whereas the clearance between the two frames is 12 mm.

The flow rate per unit area is assigned manually by a hand wheel which can be rotated to adjust the width of the flute roller exposed to the bottom valve. However, the feeding rate is usually calibrated for each seed variety only prior to the sowing process using calibration curves provided by the manufacturer for each seed variety; and should not be adjusted while operating. In Japanese farms, it is common to run the grain drill at a fixed speed which does not drop below 5 km/h, but does not exceed 9 km/h. These figures are similar to the standard speeds recommended by drill manufacturers such John Deere and Massey Fergueson (Campbell, 2002), who suggest a speed that should not exceed 6 mph (approximately 9.6 km/h). Also they go in line with a recommendation by the agricultural decision maker at Iowa State University (Edwards, 2007) who recommends 5 mph (approximately 8 km/h) as the operational speed of the grain drill.

2.2. Digital fibre sensor

The sensor used to detect the flow of seeds was an off-the-shelf digital fibre sensor (Keyence, FS-N10). It consists of a light transmitter and receiver as well as an amplifier connected by fibre