Computers and Electronics in Agriculture 142 (2017) 314–325

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Development of high-speed camera hardware and software package to evaluate real-time electric seed meter accuracy of a variable rate planter

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ARTICLE INFO

Article history:
Received 3 November 2016
Received in revised form 19 August 2017
Accepted 9 September 2017
Available online 18 September 2017

Keywords:
Precision agriculture
Seeding accuracy
Electric seed meters
High-speed imaging
Singulation
Rate control

ABSTRACT

Electric drive seed metering systems have become common for planting row-crop seed to accommodate increased machine size and planting speeds and to allow individual row unit-control that enable site-specific planting for spatially sensitive areas and contour farming. Seed singulation (a measurement of singulated seeds, misses, and multiples) is critical requirement when adopting high speed planting. However, current planting controllers fail to indicate whether singulation errors occurred due to operator-based behaviors such as speed changes, headland operation, point rows and contour farming at varying speed transitions (accelerations/decelerations). Therefore this study was conducted to understand a seed metering system's ability to singulate seed under typical scenarios with specific objectives to (1) quantify electric seed metering accuracy using high-speed imaging and (2) identify machine operating states that impact seeding accuracy. A Horsch Maestro 24.30 planter was sent commands to plant at constant speeds of 7.2, 9.7, 12.0 kph while accelerating/decelerating at 2.4 and 4.8 kph/s from/to a stop and between speeds. The planter was sent commands to plant around contours at varying radii (20, 40, 80, 150 m) at varying speeds (i.e., 0, 2.4, 4.8, 6.4, 7.2, 9.7, 12.1, 12.9, 14.5, 16.1 kph). Simulations were conducted at two rates (44,550 and 89,110 seeds ha^{-1}). A high-speed imaging system was developed using LabVIEW to record real-time seed meter singulation at 300 frames/s by combining planting machine states with seed tube sensor data and vision based seed measurements to quantify single count seeds, misses, and multiples. When planting from 2.4 kph to 16.1 kph, results showed an average singulation of 98.45% where errors nearly doubled with fast accelerations and decelerations and abrupt changes such as a shift during headland turns. Overall, planting above 1250 seeds per minute resulted in an increased number of singulation errors. The vision based measurements were within 0.8 ± 0.2% of the commercial seed tube sensors. The seed per minute value which provided optimal seed singulation can be used as a control parameter by technology users and manufactures to select optimal operating parameters to achieve target singulation rates. The methodology provided optimal machine conditions and operator behaviors to achieve a target percent singulation by identifying scenarios which increase singulation by minimizing misses and multiples.

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1. Introduction

Today, many farmers are transitioning from conventional planting systems to newer technology capable of operating at increased planting speeds to improve productivity and reduce time spent in the field. Increased productivity from advancing planting speeds also benefit the rising trend in large scale operations which have a larger number of acres to plant within a given planting window (Miller et al., 2012; Staggenborg et al., 2004). Advances in planting productivity help producers cover the same amount of acres which saves on the cost of owning and operating machinery and labor expenses. In addition, machine control capabilities provide additional benefit to automatically and accurately controlling the desired seeding rates on a spatial scale which can potentially enhance management potential and productivity of currently arable land (Mangus et al., 2015). The improved management practices and efficient application of crop inputs can sustain

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http://dx.doi.org/10.1016/j.compag.2017.09.014
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production growth and increase environmental stewardship (Sharda et al., 2010).

Since the advent of mechanical planting technologies in the late 1800s, singulating seed meters have been driven via ground drive wheels. Ground driven mechanical planters serve as an effective planting technology by providing a varying row unit speed that react real-time to speed based changes during field operation (Yeon and Shaw, 2004). Singulating seed meters have two inputs to regulate seed planting: application rate (plant population) and planter travel speed (Miller et al., 2012). Studies have exposed the importance of uniform seed spacing and seed depth control to maximize seeding inputs (Hao et al., 2017; Miller et al., 2012; Nielsen, 1996; Yazgi, 2016) and the interception of sunlight for energy for optimal yield potential (Koller et al., 2013; Shrestha and Steward, 2003). As reported by Precision Planting Inc. (2014), a 1% decrease in percent singulation decreased the yield potential by 150 kg/ha. Analyzing seeding performance relate the actual seeding rate to the theoretical seed spacing resulting in terms of percent singulation, which is a function of seed metering precision (Koller et al., 2014), accuracy, miss index, and multiples (Hao et al., 2017; International Organization for Standardization, 1984; Miller et al., 2012). For comparison purposes, this article describes the 'row unit' and 'singulating seed meter' by following the definition per ASABE Standard S506 (American Society of Agricultural and Biological Engineers, 2014) and referencing the ISO 7256/1 (International Organization for Standardization, 1984) to describe a miss or multiple (double or triple).

While mechanically ground driven planters serve as an effective planting technology at traditional speeds, concerns arise because slippage of ground wheels and vibrations from drive chains can impact planting accuracy, especially at higher planting speeds (Lacomi and Popescu, 2015; Yang et al., 2015). In addition, ground drive-wheels typically control singulating seed meters of at least two or more row units and in most cases control all row units across the whole planter tool bar. As a result, each row units' planting speed is the same across the planter or driven planter section which in turn fail to account for angular speed differences across the planter bar when planting on contours. Consequently, seed spacing error occur when planting on contours as the planter's inside row spacing is reduced while the outside row spacing is beyond the recommended increment. Planting errors such as over- and under-applied seed rates have been shown to increase with larger planter size (Nielsen, 1996) and planter speed (Shrestha and Steward, 2003). Furthermore, as planters increase in size and travel speeds, irregular shaped fields create concerns because of the chance of misses and multiples. These off-rate errors and unintentional inputs contribute to increased production costs (Mangus et al., 2015; Velandia et al., 2013).

Irregular shaped fields create a need for automatic section control (ASC) technology to signal individual row unit control. Individual row unit control is used to maintain target application rates, minimize overlap and decrease off-target application rates within headland turns, point rows, areas of field already seeded, terraces, and groundwater sources (Fulton et al., 2011; Mangus et al., 2015). In order to achieve individual row unit control for site-specific applications and to meet the growing demand for higher planting speeds, planter manufacturers have turned to electronic drive seed metering systems that have functionality to resolve mechanically ground driven limitations as previously described. Electronic seed meters eliminate the need of mechanic friction to control and singulate the seed typical in mechanically driven seed meters (Kamgar et al., 2015). Electric seed metering controllers can regulate row unit seed metering speed to maintain planting rate during speed changes and respond at a rate required for higher planting accuracy (Deere and Company, 2016; Lacomi and Popescu, 2015). Electric seed metering technology on individual row units introduce benefits over previous metering technologies due to their modular design, easy manufacturing and service, minimal moving components that wear or need replacement, and ability to control individual row units (Lacomi and Popescu, 2015). Individual row units with automatic control enable many site-specific management techniques without the need for additional hardware which include: contour farming, individual point-row control, and prescription seeding rates. Site-specific planting technology using ASC utilize electric seed metering systems to plant at predetermined field locations, population seed rate while compensating for planting speed (Deere and Company, 2016; Velandia et al., 2013). Hence, automating electronic controls have enabled machine control to surpass a human's capacity for precision (Mangus et al., 2015). In general, ASC has been proven to pay for itself in less than 2 years by saving on inputs by 1–12% across the field with an average savings of 4.3–7.0% savings specifically on seed cost (Fulton et al., 2011). Moreover, other studies show that over-applied (or double-planted) areas ranged from 0.1% to 15.5% depending on the field size and shape where the adoption of this technology could save from $4 to 26 per ha (Velandia et al., 2013). Automatic machine control with electric seed meters has enabled planters to maintain desired pass-to-pass distance and increase coverage area, travel speeds, and overall machine size due to automatic control not previously possible under manual user input.

To meet the demand for increased seed metering accuracy and decreased production costs, advancement in seeding technology has been focused on uniform seed spacing (Glenn and Daynard, 1974; Koller et al., 2014; Miller et al., 2012; Staggenborg et al., 2004; Yazgi, 2016). Uneven plant spacing result in one plant producing less grain/yield and competes for nutrients and moisture from the other plant(s) (Carlson et al., n.d.; Hao et al., 2017). Uniform seed spacing has been found to be directly related to higher crop yields predominantly at high seed rate populations where a reduction in yield was directly related to increased plant-to-plant spacing variability (Staggenborg et al., 2004; Yazgi, 2016). Inter row plant spacing variability was found to account for 25% of the yield variability (Staggenborg et al., 2004) while a separate study found plant-to-plant row uniformity increase yield potential by 20 bushels/acre (Carlson et al., n.d.).

Investigations have been conducted to quantify the influence to crop yield and seed spacing based on the type of furrow opening components (Carlson et al., n.d.; Yazgi, 2016), seed drop height (Yazgi, 2016), and the impact of furrow opening downforce (Karayel and Sarauskis, 2011). The actual seed spacing, seed velocity, exit location, and trajectory angle have been evaluated based on the seed trajectory leaving the seed tube (Koller et al., 2014). In addition, furrow closing systems have been investigated to influence crop stand and subsequent crop yield (Crabtree and Henderson, 1999). Additional studies have found a significant impact to seeding accuracy and uniformity has been due to the singulating seed meter and the entry into the upper portion of the seed tube (Moody et al., 2003; Staggenborg et al., 2004) where studies show an impact of seeding accuracy is due to seed tube design and geometry where seed tube wear and overall condition have a direct impact on seeding accuracy (Kocher et al., 2011; Yazgi, 2016). High-speed imaging systems have been used to analyze seeding delivery systems (Hao et al., 2017; Singh et al., 2005) where optical sensors have been used to analyze the seed spacing accuracy on belt metering systems (Kocher et al., 2011), seed size uniformity (Casady and Paulsen, 1989), and quantify seed spacing and variability as a seed enters and leaves the seed tube thus impacting the subsequent furrow spacing with increased planter travel speed (Moody et al., 2003).

Although studies have used imaging to analyze singulating seed meter accuracy and planting uniformity, no studies have been con-

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