Automatic working depth control for seed drill using ISO 11783 compatible tractor

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Abstract
The reliability of field work documentation and the functionality of PA systems set critical requirements for the instrumentation of agricultural implements. Precision agricultural machinery should be easy to use and operated without the need for automatic online controls that are map-based. The aim of the study was to develop automatic depth control system for a drill using an ISOBUS compatible tractor. In this paper, the instrumentation, the depth control model, and the control system of a prototype combine drill is described. A preliminary survey was carried out to choose sensors for the instrumentation of working depth control in a Junkkari Maestro 3000 combine drill. In the first phase of the research, a reliable measurement system based on multiple sensors was developed. A working depth model was then developed for the control of seeding depth. The control commands to hydraulic valves were transmitted using ISO 11783 network. In the second phase, all the sensors were calibrated indoors on a concrete floor. Field trials and measurements were carried out in during the final phase. For validating the theoretical model, the real depth of seeds was obtained from the soil profile by slicing after the germination of seeds. In the field tests automatic working depth control achieved accuracy of ±8 mm.

Keywords: control system, networked control, sensors, working depth, estimation, field tests, ISO 11783, ISOBUS

1 Introduction

Reliability of field work documentation and the functionality of precision agricultural (PA) systems set critical requirements in the instrumentation of agricultural implements. PA machinery should be easy to use and if possible, automated should work using real-time measurements performed online. Information and communication technology (ICT) assisted PA is the key technology to fulfill these demands (Auernhammer 2003, McBrantney et al. 2005). Embedding of electronics into mobile agricultural equipment has helped to enhance the functionality, efficiency and environmental compatibility of machines (Stone et al. 2008). An intelligent user friendly function of PA machinery plays a very important role in future researches. To reduce machine drivers' workload during driving and for more accurate realisation of field tasks, functions such as automatic depth control systems are needed. Different kinds of depth control systems have been developed and studied in the past. Moutzen et al. (2004) used soil wheel Linear Variable Differential Transformer (LVDT) sensors to determine the height of the machine frame form the soil level. According their study, soil wheel sensors can be used in fields covered with stubble and, plant residue where the ultrasonic sensors incorrectly measure the height of the equipments frame from the soil surface. Adamchuk et al. 2004 used ultrasonic sensors for determining tillage depth. Saeys et al. (2007 and 2008) develop depth control system for shallow manure injection into soils. In their system, ultrasonic sensors were used to measure the distance between the injector frame and the soil surface. However, automatic working depth control for drills, which utilizes tractor's hydraulic valves via standardized ISO 11783 network with an ISO 11783 (ISOBUS) class 3 tractor, has not yet been documented.

The aim of this study was to develop an automatic depth control system for a drill using an ISO 11783 class 3 compatible tractor. To achieve this aim, an accurate and reliable online measuring system, and a working depth model for determining seeding depth was developed. Furthermore, an automatic depth control feature was developed for the electronic controller unit of the drill. The functionality of the depth control system was also evaluated.

2 Materials and methods

2.1 Seed drill and tractor combination

For testing the automatic seeding depth control system, a Junkkari Maestro 3000 combine drill and a Valtra T190 ISOBUS compatible tractor were used. In the Junkkari Maestro 3000 combine drill, toothed wedge roller coulters (with weighing force of 6 to 140 kg) were used for both seeding and local fertilizing. Sowing depth is adjusted by changing the length of the lift cylinders. When lowering the machine into the sowing position, the weight is relayed to the coulters with the springs. The separately weighted bearing wheels divide the machine's weight evenly over the entire sowing width.

2.2 Sensors and measurement system

Location of sensors in the measurement system is given in Figure 1. Soil surface were measured using two soil wheels installed with rotary position sensors (Positek P502.30AJ) and two ultrasonic rangers (Siemens 3RG6113-3BF00 and Pil P43-F4V-2D-1C0-180E). The rotary position sensors were used to measure the changes in the angle between the soil wheel frame and the body of the drill. The drill has 32 coulters in all. Counting from the left, blade sensors (Blade 60mm from Gill sensors Ltd) were installed on the 5^{th}, 12^{th} and 27^{th} coulters to measure the angle changes between the frame of the coulters and the body of the drill. Two ultrasonic rangers were installed in front of the fifth coulter. In addition, a measuring wheel was installed in front of the 5^{th} and 27^{th} coulter (Figure 1). The position of the lift cylinder was also measured using a blade sensor. All the sensors were configured for optimal measuring ranges.

Panasonic Toughbook CF-18 and National Instrument's Usb-6009 data card were used for data collection. Measurement programming was carried out using LabView 8.0. A measurement frequency of 50 Hz was used during field trials. Trimble 5700 RTK-GPS receiver accuracy of 2 cm was used for position measurements. The GPS receiver was positioned at the middle of the working width, and mounted on top of the drill to coincide with the front coulters. This position is labelled as the ZERO-point in Figure 1. This positioning procedure enabled the localization of the seed rows during the field tests. Position correction for the sensors used in the depth control system is shown in Figure 1.

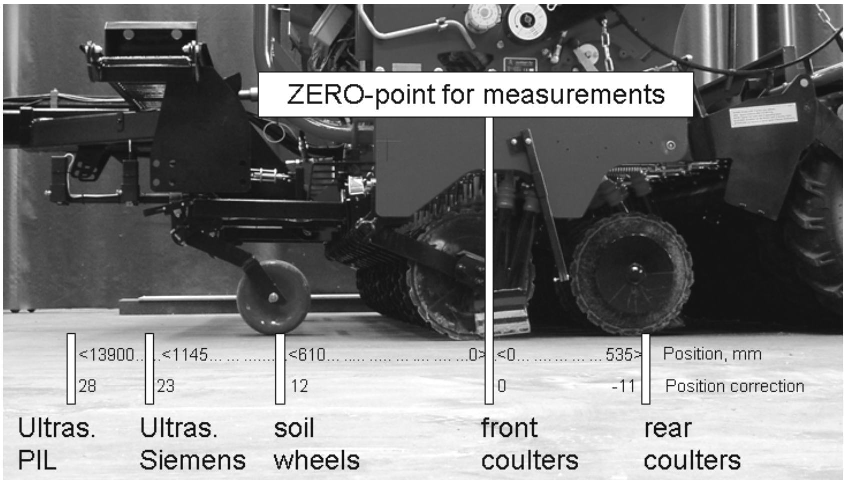

Figure 1. Position of sensors used in the depth control and measurement system of the drill.

2.3 Sensor calibration

All the sensors were calibrated indoors on a concrete floor. Both the tractor and the drill were elevated 100 mm from concrete floor. Then the lift cylinder was open 24 mm. This position of the lift cylinder was the reference *calibration position of the drill*. The position of the floor was *the calibration level* and the 100 mm elevated position represented *zero drilling depth position* when no drilling was taking place. The sensors were calibrated for a range of 0-100 mm representing the drill working depth, 100-120 mm representing crop residue and soil lumps. To determine the relationship between the measured signals from sensors and the distance from the floor, slides of plywood were placed step by step under the coulters, the measuring wheels, and the ultrasonic sensors. In the calibration, a third degree polynomial function was used for each measurement. Third degree polynomial is described as:

$$\boldsymbol{C = aV^3 + bV^2 + cV + d,} \qquad (1)$$

where $\boldsymbol{V}$ is the explanatory variable (output voltage from the sensors, volts) and $\boldsymbol{C}$ is the dependent variable (height from floor, mm), and a, b, c and d are parametric constants.

When the drill was at the calibration position it was totally horizontal. However, when the height of the lift cylinder was changed from the calibration position, the drill's orientation changed, therefore an inclination correction factor between the soil wheels and the coulters was needed (Equation 2).

In the preliminary field trials, it was observed that measurements from the ultrasonic rangers underestimated the distance between the soil and body of drill. Crops, crop residue and lumps of soil caused inaccuracies in the ultrasonic rangers, resulting in measurements lying outside the range the model. Saeys et al. 2007 used ultrasonic rangers in their depth control system but they implemented the rangers behind the coulters to minimise interference of crop and lumps of soil. The preliminary trials in this research showed that it was not possible to implement ultrasonic rangers in front or behind the coulters of the Junkkari maestro 3000 combine drill.

2.4 Working depth model

Data obtained from the sensors during the preliminary field trial were used for developing the working depth model. In the preliminary field trials spring wheat was sown to seeding depths of 30 and 40 mm. Before the trials, all the sensors were calibrated as described in section 2.3. A low pass filter was used to eliminate noise signals from the raw measurements. In addition, the locations of all measurements were synchronized to the position of the front coulters to make estimation of the model more accurate (Figure 1).

The relationship between the measured signals from the sensors and distance from the calibration level (100 mm below tractor and drill) observed during the calibration was used in the working depth model as the virtual position. The working depth model is presented in equation 2. In the model, the distance difference from the soil wheels ($\overline{M}_i$) and the coulters ($\overline{C}_i$) to the calibration level were used (Figure 2). When the position of the lift cylinder changes from the calibration position, the inclination correction factor *(I)* affects the estimation of working depth. Correction factor *(H)* for systematic error was included in the equation. The correction factor catered systematic errors observed during field trials as a result of soil properties such as softness of the soil. The control system was built such that, the systematic correction factor could be easily changed using the user interface (ISO 11783 virtual terminal) of the drill. The working depth is determined as:

$$WD = \overline{M}_i - \overline{C}_i + I + H \qquad (2)$$

where,
WD = working depth in mm.
$\overline{M}_i$ = average measurements of soil wheels from the calibration level in mm.
$\overline{C}_i$ = average measurements of coulters from the calibration level in mm.
I = inclination correction factor between the measuring wheel and the coulter in mm.
H = correction factor for systematic error in mm.

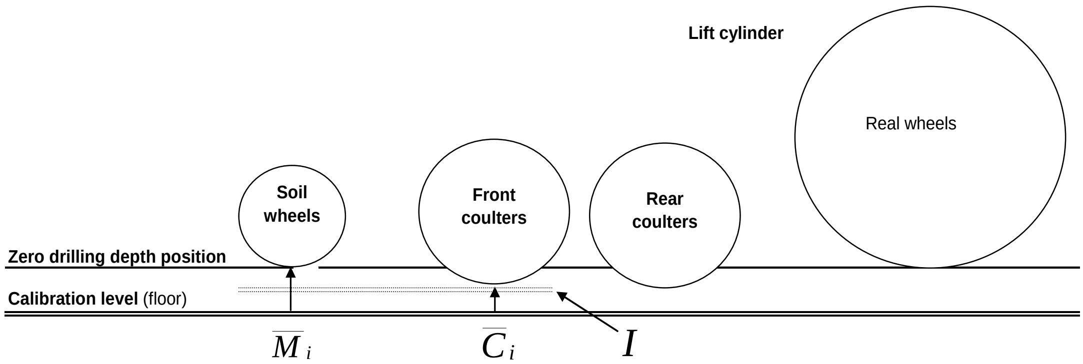

Figure 2. Position of measurement wheels and coulters from the calibration level, and model parameters. *M* is distance from the soil wheel to the calibration level, *C* distance from the coulter to the calibration level, and *I* is the inclination correction factor.

2.5 Depth control system

The working depth is controlled by changing the height between the drill and the supporting wheels by adjusting the lift cylinder; as the force to coulters depends on the height through the supporting springs. Information from the 6 sensors and the developed working depth model is used to calculate the working depth in the control system in real time.

The developed working depth measurement system, the model and the control system were used in the drill's IECU. The control system of the drill was ISO 11783 compatible. The prototype control system was based on a miniature-PC (VIA Epia), a USB-CAN adapter and a Labjack I/O board. In the developed control system prototype no extra hydraulic valves were installed on the implement, but the ISO 11783 class 3 tractor's hydraulic valves were used over the network.

In the control system, two feedback controllers were used in cascade manner. The inner controller is for mechatronics; it controlled the opening of the lift cylinder using a PD-controller. In outer loop, the PI-controller commanded the set point of the lift cylinder controller. Inner controller was tuned using data based system identification (first order dynamics + lag + delay) and tuning rules for integrating the processes (Eriksson et al., 2009).

2.6 Field validations

In first phase, the prototype drill with the new depth control system was evaluated in the spring 2008 at Kirjava field (60º 25' N, 24º 19' E) in Southern Finland. The test field was harrowed evenly to a depth of about 20 mm. Malt barley was then sown to seeding depths of 20, 30, 40 and 50 mm. In addition, a manual test run (with the lift cylinder at the calibration position) was performed. The second test phase during autumn 2008 focused on the validation of the measurement system and working depth model in the Rinne field (62º 27' N, 24º 21' E) in Southern Finland. The test field was harrowed to a depth of 60 mm to improve the homogeneity of the soil structure. Winter wheat was sown to seeding depths of 20, 30, 40 and 50 mm. Also manual tests run (lift cylinder in calibration position) were performed. During both field trial phases, similar measurement setups were used. Five test runs were carried out during the field trials. A driving speed of 10 km h^{-1} was used. The measurement frequency was 50 Hz and working depths were determined at intervals of 56 mm. Malt barley and winter wheat were sown using a seeding rate of 240 kg ha^{-1}. The distance between the seed rows was 13 mm. By using a measuring frequency of 50 Hz, the reliability of synchronization between the signals from the sensors and seed position was assured.

Two cross-line positions perpendicular to the seeding rows were located using the GPS positioning from drill. Due to the effect of tire tracks left after the cross-line position determination, the measurement of the real seed depth by hand was moved 2 m away from the cross-line (Figure 3). On each seeding row, the real seed depth was measured for a 2 m length.

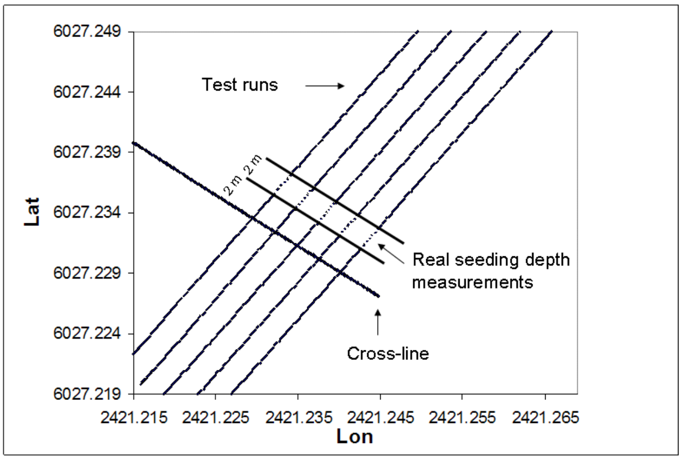

Figure 3. Locations where the real seed depths were determined.

For validating the theoretical model and the depth control system, the real depth of seeds measured by hand was used as the reference. Depths of seeds were analyzed from the rows where the 5^{th} coulter of the drill had sown. Seeding depth was determined by hand as the distance from the soil surface to the seed (Figure 4). Shoots were taken from the soil by hand site-specifically and the distance between seed and soil surface measured using a measuring rule (Figure 4). Shoots were uprooted in small groups of 3 to 5 plants at intervals of 100 mm totaling 20 samples per site.

Figure 4. Determination of real seeding dept by hand.

3 Results and discussion

3.1 Validation of the depth control system

The correction factor during the field trials for systematic error was zero. A plot of the real depth of seeds and estimated working depth model for the manual, 30 mm and 40 mm test runs as a function of the travel distance is shown in Figure 5. The estimated working depth grew deeper during the manual test drive. Even though the Kirjava field was very even, it seemed that the soil type was not the same over the field. In test runs 30 mm and 40 mm the depth control maintained the required seeding depth. When the drill worked in softer soils, the depth control adjusted the lift cylinder position according to the estimation of the depth control model. Large variation was, however, observed for the real depths of the seeds. According the field tests (Figure 5) automatic working depth control achieved accuracies of ±8 mm. According the Figure 5, the real depths of seeds were deeper than the bottom of the coulters in softer soils. This was attributed to the fact that in softer soil, the coulters had enough force to split up soil particles so that seeds were able to go deeper to the bottom of the coulter.

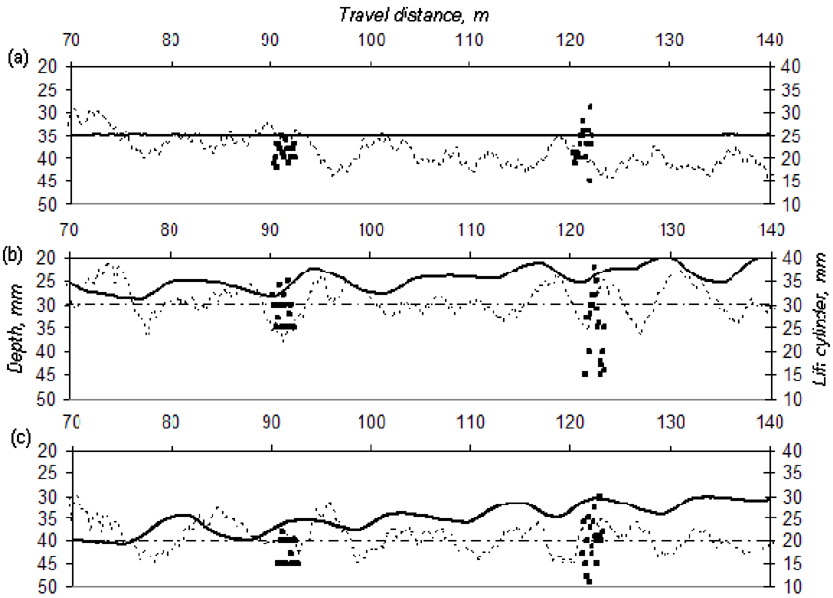

Figure 5. Results of test for the control system, (a) results of the manual test run, (b) and (c) results from test runs 30 mm and 40 mm. Solid line describes position of the lift cylinder. Dot lines describe working depth estimated by the model. Square plots represent real depths of seeds.

3.2 Validation of the measuring system and the working depth model

Autumn 2008 was remarkably wet in Finland therefore part of the Rinne test field where the real depth of seeds were to be measured was under to water. Finally one replicate of real depth of seeds from the each test runs were measured. Results from test run (30 mm seeding depth) as a function of the travel distance (total travel distance 32 m) are shown in Figure 6. Figure 6 also shows the plot of the real working depth measured by hand where the 5th coulter seeded. The solid lines show the seeding depth estimated by the model using all the sensor information. The dotted line shows the seeding depth estimated from the sensors attached to the 5th coulter on the drill.

Table 1 shows the results of the working depths at 2 m measured by hand, estimated by the model, and the average over the whole 32 m driving distance. For the 2 m cross-line location, the depth model achieved an accuracy of ±5 mm in the 20 to 40 mm seeding depth test runs. When target depth was 50 mm real depths of seed were deeper than the coulters bottom like in validation of depth control system (Chapter 3.1). It seems that there was the same phenomenon like in Kirjava field. Coulters have enough force to splits soil particles up so seeds may go deeper than bottom of the coulter. Even when the test field was harrowed to 60 mm it seems that in the test run 50 mm coulters did not have enough weight to realize the target depth even though the position of the lift cylinder was at bare minimum (0 mm).

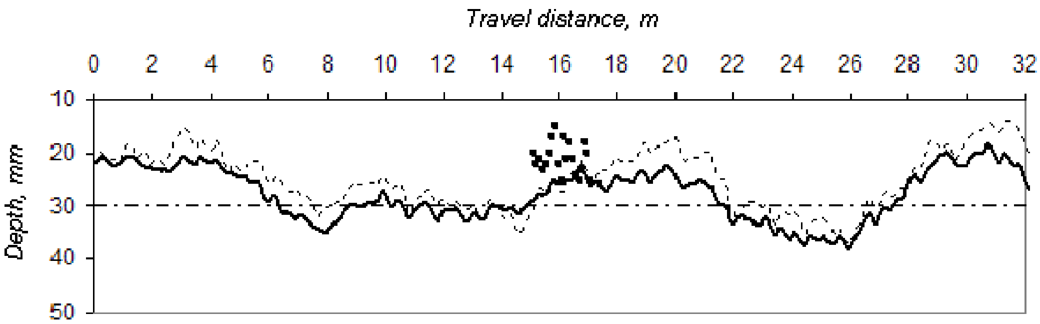

Figure 6. Seeding depth estimated by model (solid) and measured by hand (square) at a seeding depth of 30 mm. Dot line is the seeding depth estimated by the model using 5th coulter's measurements.

Table 1. Results from the field trial of validation of the measuring system and working depth model.

	Measurement at cross-line (2 m)		Measurement at driving row (32 m)
Test run	***Real depths of seeds measured by hand, mm***	***Working depth estimated by model, mm***	***Working depth estimated by model, mm***
50 mm av.	40.5	36.4	38.5
50 mm sd.	4.6	0.8	4.0
40 mm av.	33.9	34.1	36.8
40 mm sd.	4.2	0.9	2.9
30 mm av.	21.0	25.6	27.7
30 mm sd.	2.9	1.7	4.9
20 mm av.	17.1	16.5	20.6
20 mm sd.	2.0	2.8	5.3
man av.	36.7	39.7	39.1
man sd.	4.6	2.0	3.9

4 Conclusions

The following conclusions were obtained from the study:

- Working depth model were developed for the ECU of drill. The dynamic behaviour of the depth control system varies during drilling. Differences in soil type and structure were the main cause of variation.
- The automatic working depth control for seed drill was developed. ISO 11783 compatible tractor prototype drill combination was used and demonstrated successfully in field trials. Hydraulics of tractor was commanded by ECU of the drill.
- According the field tests (Figure 5) automatic working depth control achieved accuracies of ±8 mm.
- According the field test (Table 1), the working depth model descried the real depth of seeds to an accuracy of ±5 mm.
- Based on the variation in soil type on the field, correction factor observed due to the sinking of the soil wheel was sometimes required. Therefore the model consist parameter H for systematic error that was possible to update through the user interface (ISO 11783 virtual terminal) of the drill.

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