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Development of an Opto-Electronic Monitoring System for Crop Planter Seed Metering Unit

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Abstract: The main objective of a seeding machine is to put seeds at a desired depth and spacing within the row. Seed spacing uniformity is one of the most important criteria in evaluating planter performance. Therefore, the objective of this research work was to develop an Opto-electronic monitoring system for the assessment of a mechanical planter seed metering unit performance. The developed system was used to monitor seed flow from the metering system of the row crop planter and to determine seed spacing. The developed system comprised of an optoelectronic sensor for seeds detection, a rotary encoder for forward speed and seed position measurement, amplifiers for adjusting sensors signals, a microcontroller for synchronizing sensors signals and a PC for operating the program and displaying process. The opto-electronic monitoring system has been successfully developed and tested on chickpeas seeds at two operating speeds (1.3 ms^{-1} and 1.9 ms^{-1}) and three metering system gear combinations. Both seed numbers and positions of the dropped seeds were assessed. The results indicated that the developed system can be accurately used to detect seeds flow from the metering system with strong linear relationship between the system measured and the actual measurements (R^2 = 0.993). Furthermore, the system could be easily modified to measure seed spacing on-the-go in order to monitor both seed flow and seed spacing. Consequently, the developed system will enhance the process of precision seed placement.

Key words: Opto-Electronic Sensor · Precision Farming · Seed Metering · Seed Spacing

INTRODUCTION

The main objective of a seeding machine is to put seeds at a desired depth and spacing within the row. Uniform seed spacing and depth result in better germination and emergence and increase yield by minimizing competition between plants for available light, water and nutrients; and the quality of horizontal and vertical distribution of seeds is influenced by row spacing, sowing depth, soil conditions, seeders design, seed density and operator skill [1, 2]. Plant population is an important factor in crop production, which can affect growth and yield and this to a great extent depends on the performance of the metering mechanism. Robinson *et al*. [3] studied the effect of uniformity of plant spacing within the row on sunflower yield and quality. They found that uniformity of plant spacing within the row affected yield, seed size and consistency of seed size in some of the sites and years of their study. Thus, both seed population and seed spacing at planting time have effects on the harvested seed yield and seed size. Examples of studies conducted to determine the effect of plant population on seed quality include projects conducted by Robinson *et al*. [4] and Johnson *et al*. [5]. Both studies found that specific plant populations provided maximum yield depending on test location. Both studies also showed that seed size generally decreased as plant population increased.

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One of the most important criteria in evaluating planter performance is seed spacing uniformity. The distance between plants within a row is influenced by a number of factors including variability in planter metering and seed dropping, failure of a seed to be dropped, multiple seeds dropped at the same time, seed trajectory and seed bounce in the furrow, as well as seed emergence factors [6]. Several researchers have published results from comparisons of planter models and field speeds for seed spacing accuracy as delivered by the planter. Mollanen *et al*. [7] compared four planter models on a grease belt test stand, each with several options, at three field speeds with three seed sizes, for a 'planter index'. They found that seed spacing accuracy differences were observed among planter models, among options within models, among field speeds and among seed sizes [8]. They also found differences in seed spacing accuracy caused by planter model, seed size and field speed. Panning *et al*. [9] used the opto-electronic sensor system for laboratory evaluation of the seed spacing uniformity of a John Deere 71 Flexi-planter, a John Deere MaxEmerge II planter and a Kleine Unicorn-3 planter. Each planter was operated at simulated planter travel speeds of 3.2, 5.6 and 8.0 km/h while planting regular-pelleted sugar beet seeds with a target spacing of 15 cm. They commented that tests in the laboratory using the opto-electronic sensor system allowed the planter performance to be determined quickly and with less variation than that obtained from field testing. Lan *et al*. [10] concluded that within the error range caused by the elevation difference between the opto-electronic photogate sensor and the grease belt, seed spacing data obtained from the two systems were not significantly different. The opto-electronic system can be used instead of a grease belt test stand to obtain rapid quantitative laboratory evaluations of planter seed spacing uniformity. The opto-electronic sensor system, with 3 mm diameter LEDs and phototransistors, worked well to obtain 508 seed spacing's for regular-pelleted and mini-pelleted sugarbeet seeds and pelleted chicory seeds. The opto-electronic system missed two seeds and detected two phantom seeds out of 170 seed spacing's with medium- encrusted sugar beet seed.

The importance of seed monitoring system is means to observe seed population planted by each planting or dispensing unit, as well as by the planting machine as whole. In the typical planting operation, a number of planters, each has a hopper for containing seeds and a chute which extends near the ground, are pulled by a tractor. If one or more of the planters becomes inoperative, it is apparent that unless the tractor operator is aware of the malfunction, a crop deficiency will result. It is not possible for the tractor operator to control the tractor and at the same time watch all of the planter units. It is therefore very desirable that the tractor operator be able to monitor the output of the planters and simultaneously control the tractor. Many types of seed monitoring systems had been designed, developed and patented. According to Schenkenberg [11], indicating system had been proposed whereby the tractor driver could watch flashing lamps which were supposed to indicate whether the planter units are operating properly. These indicating systems generally utilized a sensing device comprising a mechanical switch, which is actuated as a result of physical contact thereto by a seed passing through the chute. However, the mechanical switches that are used must be highly sensitive and serious problems with such switches have occurred by reason of dust and moisture getting into the switches and causing a malfunction. The US patent to Fathauer *et al*. [12], a wireless seed detecting and monitoring apparatus includes one or more transmitter units mounted at the seed planter and a receiver unit mounted in a monitor console located at remote location. Seeds being planted produce a signal which modulates a transmitted signal during the planting operation. A receiver is responsive to the transmitted signal and detects the modulated signal information corresponding to seeds being planted. This detected signal is then delivered to monitoring circuitry to indicate the operation of the seed planter. The US patent to O'Neall and Borovec [13], a standalone monitoring apparatus is provided for monitoring a plurality of selectable functions of an agricultural planter. This includes a plurality of seed sensors, each associated with a corresponding seed dispensing unit and generating a seed signal representative of the depositing of a seed by the memory. The monitoring apparatus is intended to monitor signals from up to 16 seed sensors.

The overall objective of this study was to design, develop and test an opto-electronic monitoring system for the assessment of mechanical planter seed metering unit performance in the laboratory. Specific objectives were:

- To design and develop a seed monitoring system which comprised an opto-electronic sensor, a rotary encoder, a microcontroller, an amplifier and a computer.
- To evaluate the performance of the developed system based on monitoring seed flow and measurement of seed spacing at various working conditions.

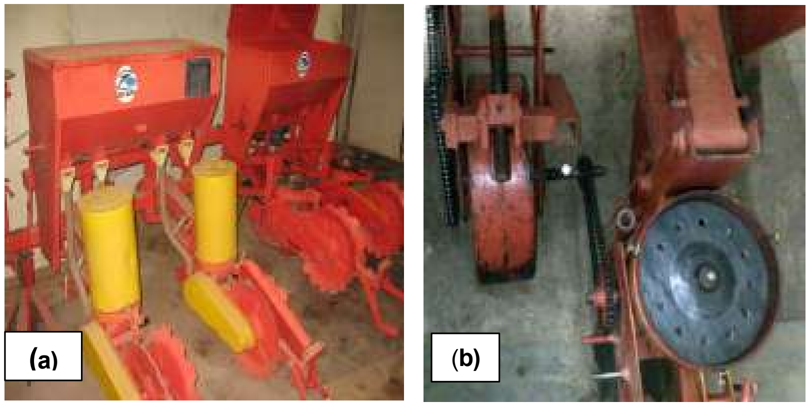

Fig. 1:(a) Test Planter (Model ATESPAR, GIAD Company) and (b) Seed metering mechanism

MATERIALS AND METHODS

Test Platform: A Mechanical crop planter (4 rows, ATESPAR, Turkey brand assembled by GIAD Company, Sudan) with fertilizer application facility was selected as the test platform (Fig. 1-a). The planter metering mechanism includes seed plates for metering seeds. Cells along the periphery of the plates were sized to match the seed dimensions, so that only one seed could fit in each cell. As each cell passing the seed tube, a spring-loaded knockout device would push the seed into the seed-tube. Plates were easily replaceable (Fig. 1-b).

Test Seeds: Chickpea seeds (*Cicer arietinum*) were used for this study. Seeds used for the experiments were sorted and graded using sieves. The seed diameter was between 3.18 mm and 9.52 mm and the average seed weight was 23 g/100 seeds.

System Description: The opto-electronic monitoring system consisted of an optoelectronic sensor for seed detection, a Rotary Encoder for forward speed and seed position measurement, an amplifiers for adjusting sensors signals, a microcontroller to synchronize sensors signals and a PC to operate the program and the monitoring the system (Fig. 2).

Experiments were carried out using the test planter (Fig. 1) coupled to an AC motor (220 Volt, 0.4 kW) via a gearbox (Fig. 3). Experiments were conducted at two speeds (1.3 ms^{-1} and 1.9 ms^{-1}). The integrated system collected multi-sensor data and store the information in database format. The different components and how they were integrated are described in the following sections.

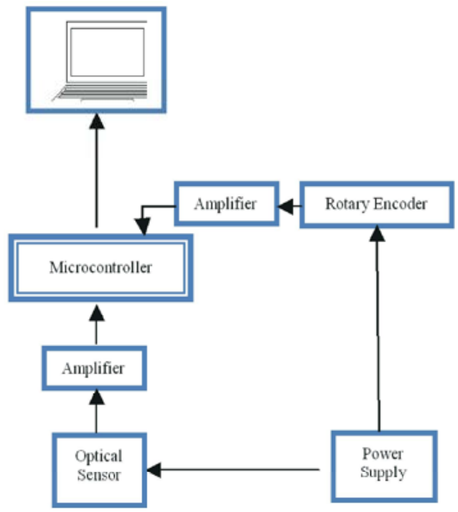

Fig. 2: Block diagram for the developed opto-electronic seed monitoring system

System Components

Opto-Electronic Sensor: The Opto-electronic sensor (OMRON Corporation, Japan) used in the system was a Digital Fiber Sensor E3X-DA-S. This unit is used to detect seeds as they exit from the drop tube. The sensor is applying a sensing distance of 1300 mm and a sensing width of 30 mm (Fig. 4-a). The Fiber Head was connected to the seed tube as shown in Fig. 4-b.

Rotary Encoder: The rotary encoder (Model E6B2-CWZ6C, OMRON Company, Japan) was used in the system to detect forward speed and the traveled distance to calculate the in-row seed spacing. The selected rotary encoder has a wide operating voltage range (5 to 24 VDC) and resolution of 200 PPR (pulses/rotation). The shaft of the rotary encoder was connected via the extended shaft in the gear and coupling (Model E69-C06B, OMRON Company, Japan) as shown in Fig. 5.

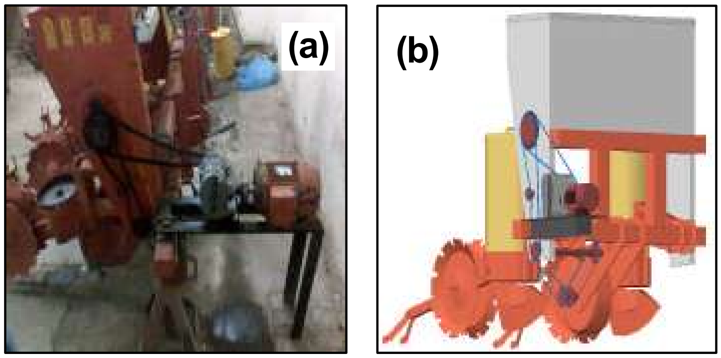

Fig. 3: (a) Experimental setup and (b) AC motor coupled to transmission system.

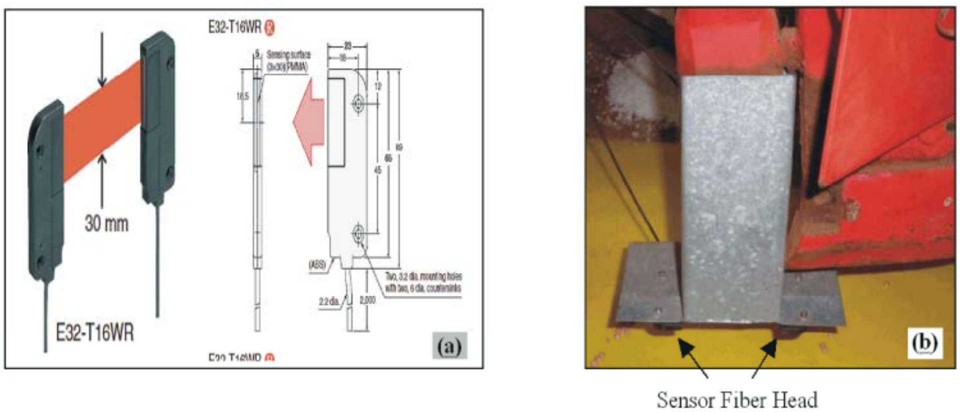

Fig. 4: (a) the Opto-electronic sensor Fiber Head and (b) the sensor connected to the seed tube.

Fig. 5: Rotary Encoder Connection.

Microcontroller: To integrate the functions of the system components an Atmel ATMega16L microcontroller was used. It has a digital supply voltage and four ports (A, B, C and D). Port A serves as the analog inputs to the A/D Converter and also serves as an 8-bit bi-directional I/O port.

Monitoring System Development: A C++ software program, to integrate the functions of the system components, has been successfully developed. Tests were conducted under stationary conditions, using chickpea seeds and with variations in ground speed using an electrical motor (220 V, 0.4 kW), jointed with a variable speed gear box giving two speeds of 1.3 ms^{-1} and 1.9 ms^{-1}. The system flowchart is shown in Fig. 6-a. The developed program was executed in the Code Vision AVR to operate the Microcontroller and the program window output was presented in Visual studio as shown in Fig. 6-b. The integrated system collects multi-sensor data and stores the information in database format.

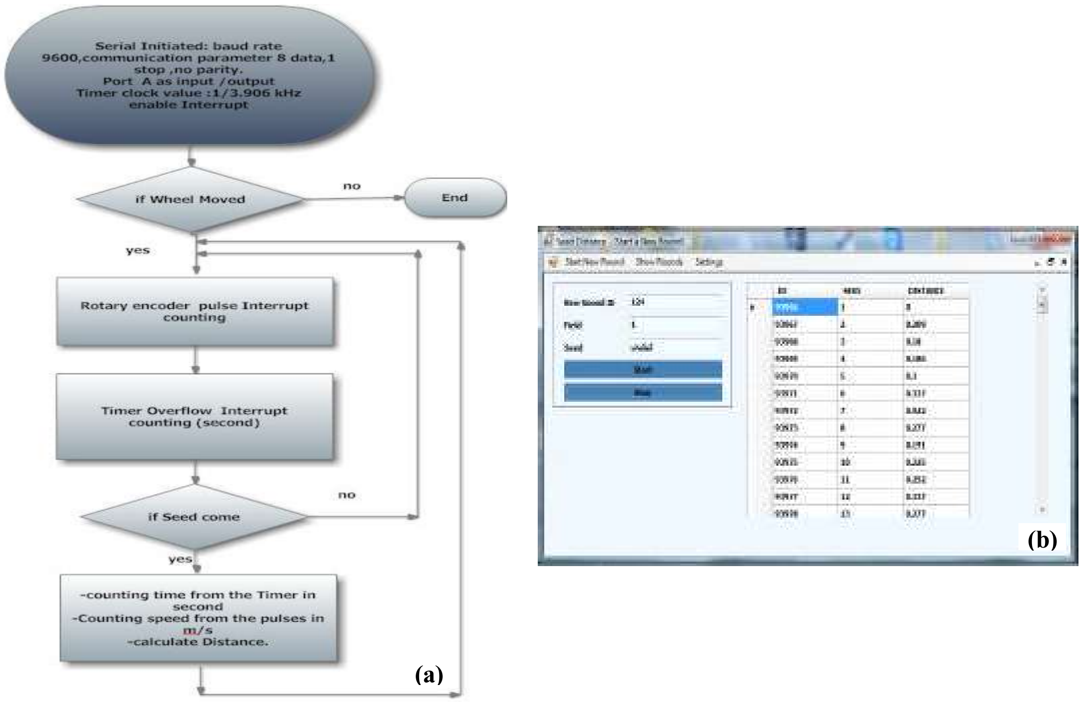

Fig. 6: (a) the system flowchart and (b) the program window.

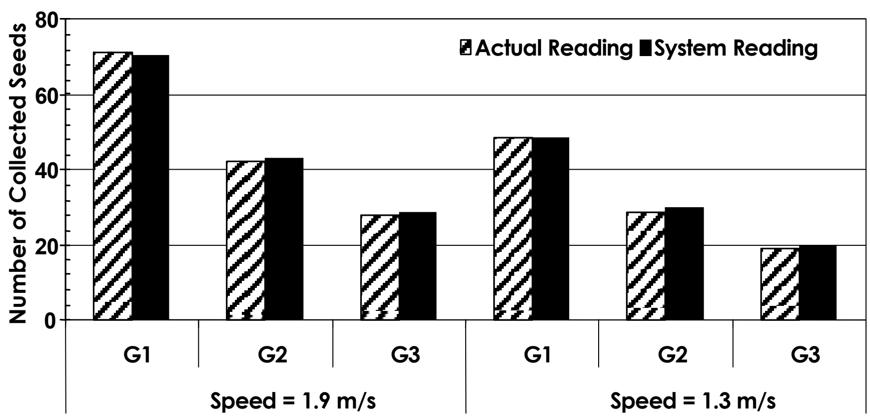

Fig. 7: Developed system readings vs. Actual seed numbers.
(G1, 2, & 3 = Gear combinations 1, 2, & 3).

System Setup and Calibration: The system components were setup, calibrated and the system performance of each component was evaluated separately. Experiments were carried out under various speeds and target seed spacings. Experiments to evaluate the performance of the developed system were conducted under two operating speeds of 1.3 ms^{-1} and 1.9 ms^{-1}. Observations were taken for three replicates at each gear ratio and operating speed. The monitoring system reading was based on the time intervals and the readings of the sensor were taken each 10 seconds.

Test Process: The Head of the optoelectronic sensor consisted of a sender and a receiver was set-up as shown in Fig. 4. The sender is placed in one side of the seed flow path while the receiver was placed on the other side of seed flow path optically aligned with the sender and adjusted to the best alignment and resolution. The Head emits an electrical signal when a seed passes between the sender and receiver. Amplifier was used to magnify the signal which recorded through the Microcontroller in the data base at the same time the signal will generate interrupt to the Rotary Encoder in the program to define

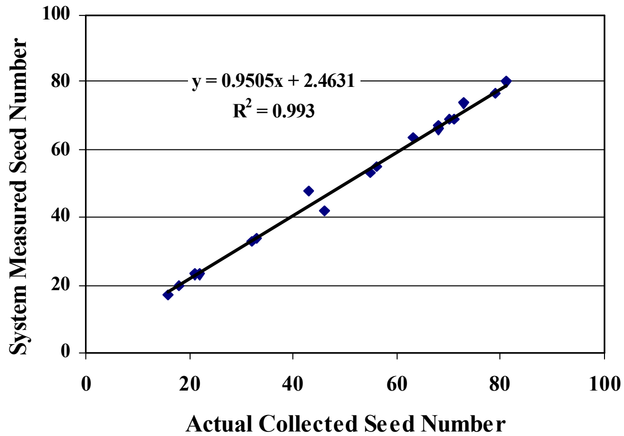

Fig. 8: Average system measured vs. Actual measured seed numbers.

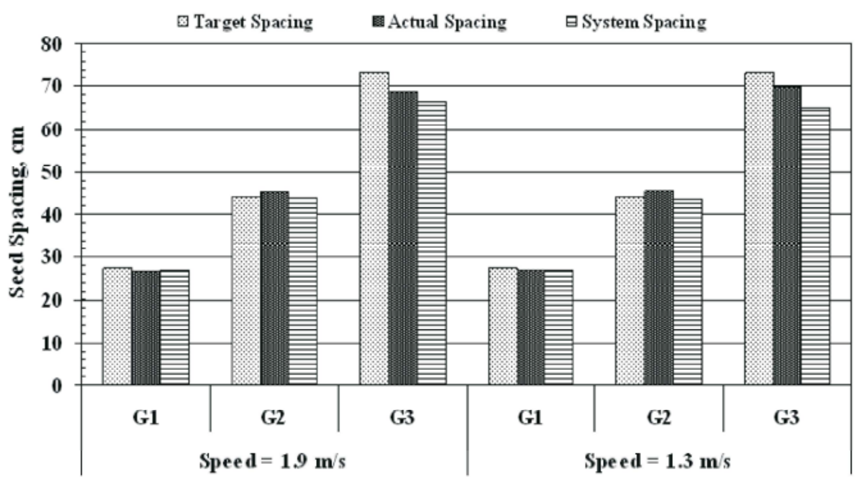

Fig. 9: Target -, actual - and system measured – seed spacing.

this point and record it in the data base and start counting from this point to calculate the spacing between the consequent seeds. Using the opto-electronic sensor will help the operator (driver) to follow the records on the monitor for immediate action against improper work indication. And the data base allows for further analysis of data which can be used for planting field operations assessment.

RESULTS AND DISCUSSION

Performance of the Developed System-Seed Detection: The developed seed monitoring system was tested against the actual seed measurement performed manually at two forward speeds (1.3 ms^{-1} and 1.9 ms^{-1}) and various metering system gear combinations and different time intervals. These experiments were conducted to assess the system performance in terms of detecting seeds flow through the opto-electronic sensor located at the outlet of the seed tube. Fig. 7 represents an example of observations for two forward speeds and three selected gear combinations (G1, G2 and G3) which were selected to give a target seed spacing of 27.5, 44.0 and 73.0 cm, respectively.

As explained in Fig. 7, seed detection by the developed system has been successfully achieved. Furthermore, the developed system was assessed towards the precision of detecting seeds dropped through the seed tube. The average results of the conducted experiments are presented in Fig. 8.

The results of the developed opto-electronic sensor system were found to be strongly correlated with the actual measurements obtained from the manual method ($R^2 = 0.993$). The linear relationship between the system measured values and the actual measured values is shown by their regression Equation 1.

$$y = 0.951x + 2.463 \quad (1)$$

Where, x is the actual number of the dropped seeds and y is the number of seeds counted by the optoelectronic sensor system. These results indicated that the developed optoelectronic sensor system can be used to monitor seed flow and to predict the planter performance precisely.

Performance of the Developed System-Seed Spacing: The developed system was also used to determine seed spacing as the elapsed time between the two seeds is counted by the system. Consequently, knowing the forward speed, the elapsed time, the number of seeds and distance travelled, the collected results could be transferred to determine the output seed spacing. Using the same observations presented in Fig. 7, the relationship between the target seed spacing (27.5, 44.0 and 73.0), the actual seed spacing and the system measured seed spacing, is shown in Fig. 9.

From the obtained results, seed flow through the seed tube could be precisely detected by the developed system. Furthermore, using the rotary encoder, the spacing between the dropped seeds could be easily measured on-the-go.

CONCLUSIONS

An opto-electronic monitoring system for the assessment of seed metering unit performance was successfully designed and developed. The developed system comprised of an optoelectronic sensor for seed detection, a rotary encoder for forward speed and seed position measurement, amplifiers for adjusting sensors signals, microcontroller for synchronizing sensors signals and a computer for operating the program and displaying the results. The developed system could be used for monitoring seed flow and measuring seed spacing quickly and precisely. The developed system seed flow measurements results indicated that the system can be accurately used to detect seeds flow from the metering system according to the strong linear relationship between the actual and the system measured number of seeds ($R^2 = 0.993$). Therefore, the developed monitoring system can be precisely used to measure seed flow and predict the performance of the planter.

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