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EMBEDDED SYSTEM FOR THE CONTROL OF LONGITUDINAL GRAIN DISTRIBUTION IN SEEDERS

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ABSTRACT

It is reasonable to consider that food production and environmental preservation, and not just any of them in isolation, are prerequisites for the very existence of the human species. From this perspective, it is evident that any strategy for environmental preservation must necessarily also consider the strategy of food production and vice versa. The challenge for technology-based companies is to create new solutions that contribute to an increase in food production, reducing the application of inputs, and without adding new areas to agricultural production. Although this new vision of agricultural production has significantly contributed to increasing food and renewable fuel production in Brazil and worldwide, there are still gaps to be filled. In this context, this paper presents the development of an embedded system for grain seeders, which consists of replacing the drive system with gears and chains of seed distributors by an efficient electromechanical system, whose general characteristics differ from other shapes and models of seed and fertilizer distributor drivers, widely known in the current state of the art. In the end, we present a case study, whose displacement value occurred in each sowing line is adjusted by a displacement calculation method, homogenizing the seed distribution in contour planting.

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INTRODUCTION

Due to population growth, the focus of modern agriculture is on food production. Several electronic resources are being coupled to machines to improve the analysis of work information and improve its quality, to make better use of inputs, conserving natural resources and avoiding waste of material and/or economic orders. This set of techniques is called Precision Agriculture, and it has been gaining strength worldwide, mainly due to the "food demand versus environmental conservation" dilemma, that is, increased productivity in the same planting area, which caused Precision Agriculture to be in great ascendancy not only in Brazil but in the world. Currently, various agricultural implements are widely known by state of the art. The object of this work arises from implements called grain seeding machines such as soybeans, corn, beans, among others. The basic function of agricultural seeding machines is to distribute in the soil, whether prepared in conventional or no-tillage form, a certain amount of seeds with a predetermined arrangement. To perform this function in the desired manner, seeders must perform the following functions: open a furrow in the soil, dose the number of seeds and fertilizers and position them in the soil, cover the furrow and firm the soil around the seeds. These implements are driven by gears, chains and shafts driven by the seeder's own wheels, for fertilizer dosing according to the soil characteristics and also sowing the pre-established amount of seeds within the furrow. This work makes an effective contribution to the increase of the efficiency of the agricultural operations through the improvement of the grain sowing process, both with the reduction of the waste of materials, inputs and operational time, and the increase of the agricultural productivity per cultivated area. This objective is made possible by the development of a system to replace the mechanical transmission to the seed disc grain seeders by electromechanical actuators, managed by an onboard electronic control system, simple to handle. This replacement allows, in addition to obtaining greater flexibility of the implement, to provide functionalities that are not possible with mechanical transmissions, such as controlling the distribution of seeds row by row, correction of the displacement difference of each row in planting contour, reduction of components and mechanical parts of the seeder.

MATERIALS AND METHODS

In this study, the implementation of an embedded agricultural system compatible with the existing mechanical systems was performed. The basic principle was the study of methods to calculate the linear displacement of each seeding line, regardless of the direction, seeder width, or position of the line. Electronic and mechanical embedded systems consist of the implementation and testing of program routines to perform procedures necessary for the creation and effectiveness of the system. The sequence of this implementation was carried out in 6 parts, which are: ECU (*Electronic Control Unit)*, Electric Actuator - Stepper Motor, Stepper Motor Drive, ECU Displacement Sensor, Displacement Sensor, and CAN Communication Network. Figure 1 shows the diagram of this proposed system.

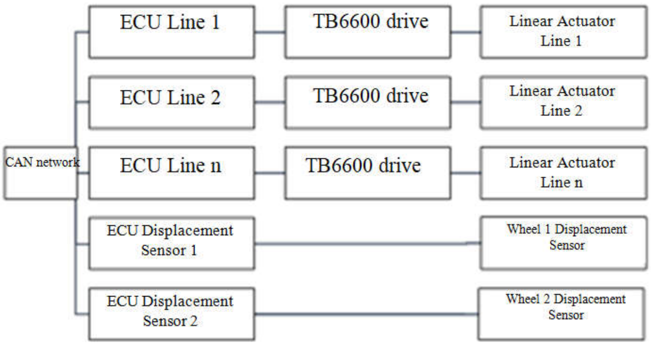

Figure 1. System Diagram

ECU - Line Controler: The line control ECU is installed on each seeding line, and it is responsible for determining the Electric Actuator (Stepper Motor) rotation in RPM (Revolutions per minute) through square wave pulses, according to the instantaneous displacement received, type of crop sown, and the seed spacing parameters expected by the farmer.

Hardware: The ECU is made up of several electronic components, the main ones being: 8-bit Microcontroller, responsible for storing the seeder parameters in ROM memory, receiving data from the displacement sensors, calculating the rotation required for the Seed Disk Dispenser, generate the signal for the Stepper Motor Drive; High-speed CAN transceiver, component that serves as the interface between the microcontroller and the physical CAN bus; the voltage regulator with 5-volt output; an 8 MHz crystal responsible for managing the microcontroller timebase, and passive components for filter, circuit protection, and current limiters.

Firmware: Firmware is the set of operating instructions programmed directly into the microcontroller used in the development of this work. This firmware is a specific class of C programming language software that provides low-level control for device-specific hardware. It provides a standard operating environment for system decision-making by performing all control, monitoring, and data manipulation functions. The firmware is stored permanently in the flash memory of the microcontroller, not being able to re-read the machine code after the burning process. As shown in Figure 2, the complete ECU program cycle is divided into 5 parts, and this cycle is performed once per second, that is, using a frequency of 1 Hz.

The cycle is started from receiving the displacement values provided by the displacement sensors by the CAN network. Then, the microcontroller performs the displacement difference calculations between the planter wheels 1 and 2 to determine if the seeding takes place in contour or not. After performing this calculation, the firmware calculates the specific displacement for the line on which the ECU is loaded. With all this information ready, coupled with the operating parameters set by the system operator, it is possible to determine the number and period of pulses for the Motor Drive, thus generating the output signal for the Stepper Motor. At system installation, the technician must provide some parameters for proper system operation, which are: the planting line number of each specific ECU (one ECU for each seeding row), total implement width, distance between planting rows, motor to seed dispenser ratio, amount of seeds poured around the seed dispenser, and target seed rate per meter.

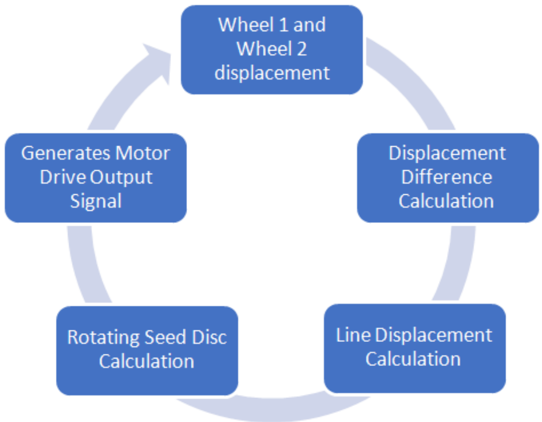

Figure 2. Firmware Line ECU

Electrical Actuator – Step Motor: As an Electromechanical Actuator for the drive of seed disc dispensers, we used devices that convert electrical pulses into mechanical movements generating discrete angular variations of the axis itself, called Stepper Motors. The rotation of such motors is directly related to the electrical impulses that are received as well as the sequence to which such pulses are applied reflects directly in the direction in which the motor rotates. The speed the rotor rotates is given by the frequency of pulses received, and the size of the rotated angle is directly related to the number of pulses applied.

TB6600HG Stepper Motor Driver: The TB6600HG Module (Figure 19) is used in this work as a stepper motor driver. The PWM Chopper has the function of converting a DC voltage to another DC, but variable and smaller than the input voltage. The switching was performed by a thyristor, which "cuts" the voltage over the circuit, where the average output voltage will be less than the input voltage, and it is controlled by the time Ton or Toff. Forward and reverse rotation control is available in 2-phase excitation modes. The 2-phase bipolar motor can only be driven by a low vibration, high-efficiency clock signal.

Electrical Characteristics: According to the characteristics presented by the TB6600 integrated circuit datasheet, this component can operate from 8 to 48 volts, making the system perfectly functional at 12 volts, tractor battery voltage. The integrated circuit has a current-carrying capacity of 4.5 Amps, enough capacity to excite the actuator sized in this work. The stepper motor has a 3.95 Amp Bipolar/Parallel Connection Current.

Excitation Settings: The excitation mode can be selected in the following eight modes using inputs M1, M2, and M3. To turn on the output, the ENABLE pin must be at high level. To turn off the output, the ENABLE pin must be low. The output changes to the Initial mode shown in Figure 20 below, i.e., when the ENABLE signal reaches the High level and the RESET signal goes to the Low level (in this mode, the status of the CLK and CW/CCW pins is irrelevant). When the ENABLE signal is low, it sets an OFF at the output. In this mode, the output changes to the initial mode when the RESET signal goes to Low level. Under this condition, the initial mode is sent by setting the high level of the ENABLE signal. And the motor operates from the start mode by setting the high level to RESET.

Coupling and Reduction: A Planetary Gear System (PGS) is used to couple the stepper motor to the seed disc dispenser. Planetary gears are characterized as a mechanical element composed of a series of rudiments, which are: the solar gear, which is the central one, the satellite gears, which are those that revolve around the solar one, and also the ring gear, part coupling to the support shaft. The planetary gear has the function of acting as a gearbox. This means that this gear captures the high motor speed and converts it into higher torque and greater positioning accuracy, ensuring better system operation.

Displacement Sensor: The displacement of the seeder is determined by the encoder type sensors, which are electromechanical devices/sensors whose functionality is to transform position into a digital electrical signal. Using encoders, it is possible to quantize distances, control speeds, measure angles, number of rotations, perform positioning, rotate robotic arms, and so on. The encoder is basically composed of a marked disc, a sender component, and a receiver (Figure 25). Optical encoders use LED as the emitting component and a photodetector sensor as the receiver. These sensors are coupled to each of the seeder's wheels, they monitor the linear displacement of the seeder and transmit the value collected within 200 milliseconds by the CAN network.

CAN Network - Controller Area Network

The CAN digital serial communication protocol was developed in the 1980s by Robert Bosch Gmb (BOSCH, 1991) to promote interconnection between control devices in automobiles. The robustness of the CAN protocol has made this technology migrate to other areas. The main features of this protocol are:

Multi-master network: The bus can be used by any unit when it is free;

- Varied communication rate, up to 1 Mbps;
- A reduced data frame, maximum of 8 bytes, for concise information exchange;
- Arbitration for access to the environment without collision;
- Bit fields in the message for error identification;
- Possibility of adding, removing, and changing devices, allowing different system configurations;

The CAN protocol has a physical layer and a data link, according to the seven layers of the standard Open System Interconnection (OSI) model (TANENBAUM, 1997). The other layers of this model are open for high-level implementation, depending on the needs of each application. Thus, several protocols are based on the CAN protocol and they define applications only in the upper layers. Figure 25 illustrates the OSI model layers and the layers used by the CAN protocol. Data communication on a network with CAN protocol is based on fixed format messages. Messages are made up of various bit fields or bit sets that have a particular function. According to the CAN protocol specification (BOSCH, 1991), there are two versions that differ in identifier field size. The CAN 2.0 A version determines an 11-bit identifier, while the CAN 2.0 B extended version determines a 29-bit identifier. Previous works (STRAUSS, 2001; SOUSA, 2002; GUIMARÃES, 2003) provide further details of this already consolidated protocol.

The CAN protocol, due to its reliability and low cost, has been widely accepted, and there are currently several devices available in the integrated circuit market. One of the advantages of the CAN protocol is the ability to withstand the error. This capability consists of relaying the message that does not appear correctly on the CAN bus. The means of transmission is simple, the most common being a pair of wires. A CAN system can work with only one wire. Depending on the application, there are other types of connections to choose from, such as radio, optics, etc. In a communications system, when a system node fails, there is a possibility that this node will block the entire system, but with the CAN protocol, this is not the case because the node can be excluded from sending and receiving on the CAN bus. Using a global clock, deploying applications in real-time is easy as it is possible to synchronize a system and this synchronization is maintained during the latency of a message. Since all modules "listen" to all messages, it is easy to implement event-driven applications. In this way, a module can be programmed to react as soon as any message appears on the CAN bus. The CAN protocol is effective for implementing distributed control systems. The arbitration method for determining message priority and the possibility of a certain number of nodes attempting to access the (multi-master) bus allows the construction of good control systems. It can be concluded that the acceptance of the CAN protocol by the automation industry is due to several factors, namely:

Low-cost;

- Robustness to electromagnetic interference;
- Ability to operate in environments with adverse electrical conditions;
- A high degree of real-time capabilities and distributed control;
- User-friendly;
- Availability of components, controllers, with CAN protocol;

RESULTS AND DISCUSSION

As explained above, in irregular and/or sloping areas, the use of erosion control techniques is required. According to Lemos e Silva (2010), the objective longitudinal distribution of seeds is compromised by the use of contour planting or curved planting applied with multiple row seeders, since the same seed wheel can drive approximately fifteen parallel lines, keeping the same amount of seeds deposited, regardless of the unit displacement or planting angle in all rows. Sowing lines at the inner end of the curve will shift less and, consequently, there will be an increase in seed density per meter (Figure 3), resulting in greater competition for fertilizer, solar radiation, nutrients, and soil moisture between plants, decreasing productivity. As for the seeding lines that are at the outer end of the curve, they will suffer a greater displacement and, consequently, a reduction in seed density per meter, with no optimization of distributed fertilizer use and low soil productivity.

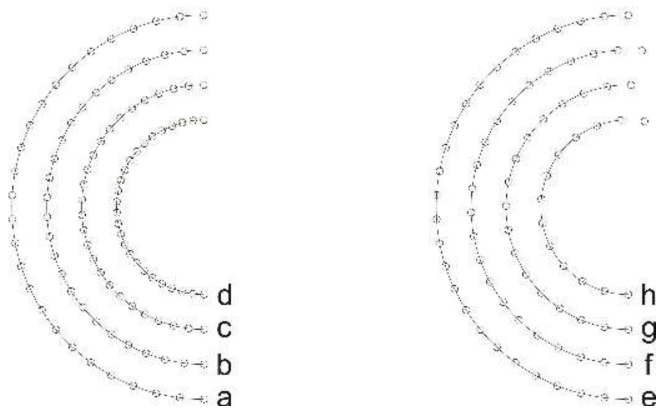

Figure 3. Contour Planting

These exposed problems caused by contour sowing can be evidenced by calculating the sowing displacement and by calculating the arc length described by each row since it is known that all seeders use a wheel in contact with the ground, which can trigger multiple seeding lines. Each of these lines will sow the same amount over a given time interval, but the displacement of each line during the curve path is different. Thus, it is imperative to calculate the arc length of each planting line so that it is possible to calculate the seed dumping rate that ensures equal spacing for all rows. Next, two methods to calculate the arc length of each plant line will be presented, namely the Arc Length method and the Approximate Calculation method.

METHOD 1 - ARCH LENGTH

Through this method, it is possible to calculate the average displacement of the seeder and also the individual displacement in the parallel rows of planting. For this, it is enough to delimit two points represented by the letters (A and B) that belong to the circumference formed during the contour planting, which is centered in (O). Besides, it is necessary to know the radius of this circumference represented by (r) and the angle formed by the line segments OA and OB represented by (α).

The length of arc AB is the measure of the distance between two points A and B, passing through the circumference, being proportional to the angle α.

To determine the length of a circumference arc, there are two cases to consider, considering that the angle α can be given in degrees or radians.

For the central angle α, given in degrees, the arc length can be calculated using Equation 1.

Equation 1 - Arc Length (Degrees)

$$C = a * \pi * r / 180^o$$

For the central angle α, given in radians, the arc length can be calculated using Equation 2.

Equation 2 - Arc Length (Radians)

$$C = a * r$$

Although the arc length method is simple, it cannot be used in a field application due to the inconvenience of not previously knowing the radius length, or the value of the angle per line that the linear displacement will cause during contour planting. However, through this calculation, one can ratify the problem of variability in longitudinal grain distribution in contour planting.

METHOD 2 - APPROXIMATION CALCULATION

The approximation calculation method is presented as a solution to the development of this work. This method consists of creating small straight lines that add up to the actual arc length. This method is based on the displacement calculation, which can be determined by means of two speed sensors installed on each seeder wheel, informing the controllers of each row the instantaneous displacement of seeder wheels, in centimeters. For the purpose of calculation, the analysis is performed by means of grids with a predetermined frequency of 1 Hz. That is, every second, the controllers of each line receive the data of distance traveled in each speed sensor of the seeder's wheel. From this, the row control ECUs can perform the displacement calculation by approximating their line by equation (3) and thus adjusting the seed rate to be distributed in a given instant time range. Displacement sensor data varies with displacement speed. For example, in a seeder with a travel speed of 2 meters per second (or 7.2 km/h), there is a grid of 2 meters of linear displacement. Each seeder row shall be driven by an electric motor and individually controlled by a previously parameterized ECU, with data on the seeding row number, total seeding row, seeder width, and distance between the wheel sensors. With these parameters previously set, upon receiving the speed sensor displacement values, the controller of each seeding line is able to determine their instantaneous displacement according to Equation 3.

Equation 3 - Approximation Calculation Method

$$DLx = \left(\frac{De_1 + De_2}{2}\right) + \left(\left(\frac{De_1 - De_2}{Dee}\right) * \left(\left(\left(\frac{TL-1}{2}\right) + 1\right) - Lx\right) * \left(\frac{Lp}{TL-1}\right)\right)$$

Where:

DLx	Linear Displacement Line X (cm)
De1	Displacement Wheel 1 (cm)
De2	Displacement Wheel 2 (cm)
Dee	Wheel Distance (cm)
TL	Total Planting Lines
Lx	Planting Line Number
Lp	Seeder Width (cm)

Case Study: An example is presented with the objective of comparing the results of the approximation method to calculate the seeding row displacement with the conventional planting method in a simulation using the hypothetical circle seeding scenario (Figure 4).

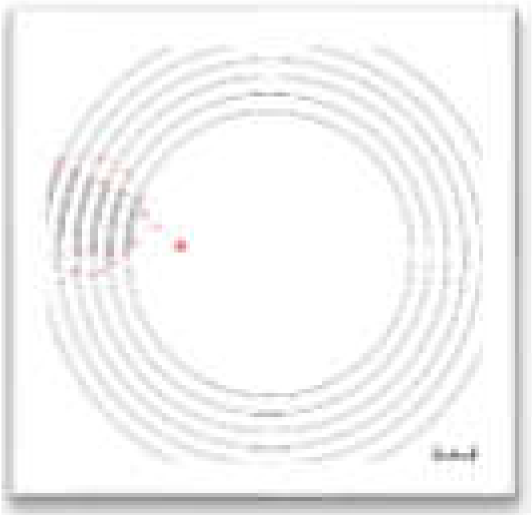

Figure 4. Grid of the study area

The sowing area in the example is a circumference, and considering a seeder containing 06 planting rows (Figure 5), it is assumed that the radius of the circumference described by the implement center point is 5 meters and the total implement width is 10 meters. Considering a planting speed of 7.2 km/h, that is, 2 meters per second, there is a grid of 2 linear meters (Figure 6).

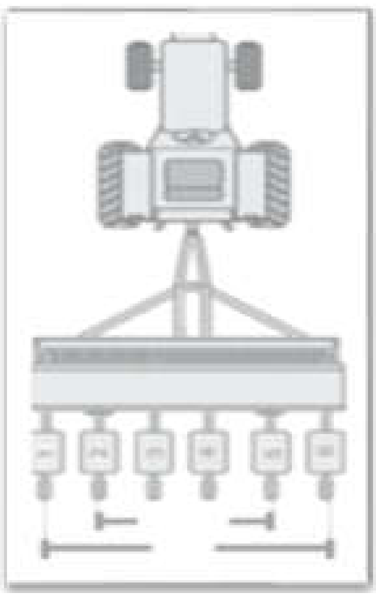

Figure 5. Planter

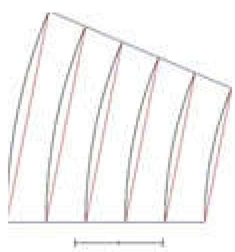

Figure 6. Grid zoom of the study area

The seeder data applied in this case study are presented in Table 3.

Table 3. Simulated Data from a Contour Seeding

Parameters	Amount
De1	226.819 cm
De2	172.862 cm
Dee	135 cm
TL	6
Lp	225 cm
Radius Line 1	612.5 cm
Radius Line 2	567.5 cm
Radius Line 3	522.5 cm
Radius Line 4	477.5 cm
Radius Line 5	432.5 cm
Radius Line 6	387.5 cm
Angle	22.9º

Based on the Arc Length Method to measure the actual displacement of each sowing row, from the above data, we compared the actual displacement result with the displacements presented with conventional seeding, that is, without any contour correction. Then, after setting the seed application rate, all rows are controlled by the single-wheel spinning mechanism and the number of seeds to be deposited. For this simulation, it was considered that the control mechanism was installed on the seeder line 2, serving as a displacement reference for all 6 implement seeding lines, so all lines apply the same amount of seeds of line 2 (Table 4).

Table 4. Conventional Seeding

	Method 1: Arc Length	Conventional Seeding		
Lx	DLx (cm)	DLx (cm)	Error (cm)	Error %
1	244.8	226.819	17.985	-7.35%
2	226.8	226.819	0	0.00%
3	208.8	226.819	-17.986	8.61%
4	190.8	226.819	-35.972	18.85%
5	172.9	226.819	-53.957	31.21%
6	154.9	226.819	-71.943	46.45%

It is observed that the error can reach 46.45%. This error directly impacts the number of seeds deposited up or down, depending on the direction of the contour or the position of the line. Analyzing only the ends, lines 1 and 6, the disparity is even greater, adding the errors to more than 50%.

Table 5. Seeding with Approximation Method

	Method 1: Arc Length	Method 2: Approximation		
Lx	DLx (cm)	DLx (cm)	Error (cm)	Error %
1	244.804	244.8046667	-0.000666667	0.0002723%
2	226.819	226.819	0	0.0000000%
3	208.833	208.8333333	-0.000333333	0.0001596%
4	190.847	190.8476667	-0.000666667	0.0003493%
5	172.862	172.862	0	0.0000000%
6	154.876	154.8763333	-0.000333333	0.0002152%

Thus, if 100 seeds were to be deposited, in fact, they would be 96 and 146 seeds would be sown in lines 1 and 6, respectively, values that are very different from what was expected by the agronomic recommendation in this case. Now, as proposed by the Approximation method (created in this project), in order to determine this individual displacement, it is necessary to install two speed sensors, one on each seeder wheel, informing the instantaneous displacement of seeder wheels in centimeters to the control ECUs of each line. These ECUs determine their individual displacement, and they deposit the number of seeds accordingly. The results obtained are shown in Table 5. In this case, the error presented for being very close to zero is practically negligible, even more, compared to the more than 46% presented in conventional seeding.

Conclusions

This system of simple implementation in seeding machines can contribute to a significant increase in efficiency in agricultural operations, as it optimizes the use of seeds, as it ensures improved homogenization of the position of the distributed grains in the soil. All the challenges and difficulties pertinent to this development were overcome with the presented solutions. In the development of linear displacement calculus applied to seeding lines from twowheel sensors, the obstacle was to take a method that could be implemented in 8-bit microcontrollers, with its limitations of variable resolution and low memory size. Since the solution found is nothing more than a simple arithmetic calculation, it was possible to easily implement it in a C programming language microcontroller. For the seeding line control ECU, which is responsible for managing the seed dispenser, development advanced after the displacement calculation was completed. In addition, the decision to use the TB6600 drive for stepper motor control made it easier to control the electric actuator with greater accuracy. In the case of the electric actuator, the use of the 12 kgf bipolar stepper motor in parallel connection was effective for the success of the project, since it was possible to precisely control the rotation, with the characteristic of fast acceleration and deceleration response, making the end result satisfactory with the project objective. The coupling and planetary reduction implemented in the solution ensured a reduction in the size of the stepper motor required to actuate the disc dispenser, minimizing power consumption and ensuring greater motor positioning and rotation accuracy. The implementation of encoders, such as speed and displacement sensors applied to the seeder wheels, ensured adequate precision to the stimuli sent during the seeder displacement. Finally, the CAN network has demonstrated its efficiency in the transport of information, due to its robustness allied to its high data transmission rate. It can be concluded that the final product of this project brings opportunities for Brazil and the world, contributing to an increase in agricultural efficiency and consequently reducing food production costs. And finally, the implementation of the Embedded System for the Control of Longitudinal Grain Distribution in Seeders and the verification of the positive points achieved demonstrates the potential of application for small and large rural products.

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