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DEVELOPMENT OF A SYSTEM FOR PATTERN OPERATIONS

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ABSTRACT Global and Local Positioning Systems are becoming more and more standard on agricultural vehicles mainly for vehicle and implement guidance. In addition to that automation systems are also being integrated. In this field an increasing need is visible to perform field tasks using certain patterns instead of performing broad acre operations. For example, orchard operations and seed plots require planting, spraying and fertilizing with respect to certain patterns. Therefore a system including hardware, algorithms and user interface was developed to allow a vehicle with automatic steering capability to also perform operations for patterns based on GPS positions. To prove the concept and accuracy of a John Deere 6000 series tractor with an automated steering system AutoTrac was equipped with a controller on the implement to trigger pattern tasks. For these tests a high speed vision system was used in combination with a self-designed geo-referenced test track. As a second step the system was tested in field operations using a John Deere 4000 series tractor with a plot seeder which delivered promising results. The results from the measurement showed, that planting and other operations can be triggered with accuracies greater then ± 3 cm. It was also possible to document the position of the plants employing the standardized ISO 11783 Task Controller documentation system. More tests with further implements will be needed to demonstrate capabilities of the system for other applications.

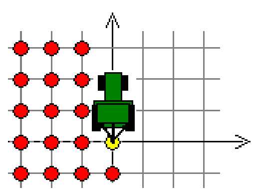
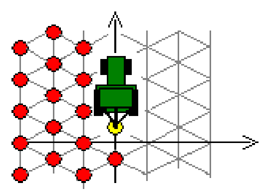
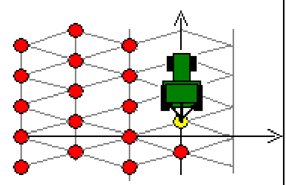
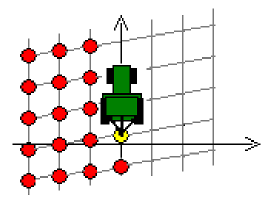
Keywords: Pattern Planting, Plot Planting, Implement Automation, Orchards, ISO 11783, High Speed Vision.

INTRODUCTION AND OBJECTIVES In the field of specialized crops like wine, vegetables or variety tests, plants are aligned in specific patterns to exploit resources like soil, water, sun, ect. as efficiently as possible [2]. Currently the efforts to realize these patterns are high. Before being able to plant, fields have to be prepared with marks on the ground showing the desired position of a plant. Only this ensures about absolute positional accuracy but takes a lot of time. The system for pattern applications was developed for automated triggering of planting operations to eliminate the effort of these preparations [1]. So in addition to the optimized crop positions, the saved amount of time is anticipated to be a big benefit of this application.

John Deere key customers worldwide were interviewed about their requirements and expectations regarding an automated planting application. Summarized the requirements of the customers were divided into two categories with respect to the desired patterns: On the one hand patterns for single plants in the field of market gardening and orchards, on the other hand plot patterns for variety test fields were to realize.

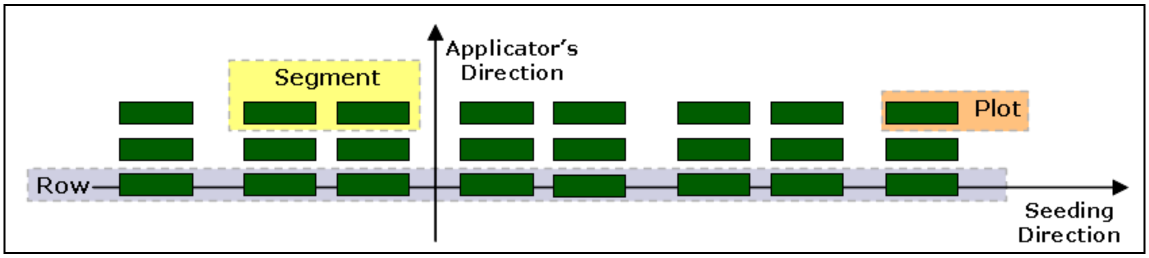
Single Plant Planting The first category deals with the idea of placing single plants whereas a previously defined pattern determines the exact position of each plant. Furthermore by knowing this position, additional nursing operations or preparations i.e. the treatment of the soil with herbicide of the position-surrounding area can be done. The single plant patterns have equidistant, straight driven rows in common. Derived from this constraint four different patterns [Table 1] were defined for the application which differ from each other by adjusting row distance and shifting plants of neighbouring rows relatively to each other. Typically for planting operations like these speeds of 1kph - 2kph are applied.

Table 1. Single Plant Patterns.

Pattern			
90 Degrees	Equilateral Triangles	Alternating Rows	Area-Integrated Angle
			
No shifts between the rows. Each plant lies with an angle of a multiple of 45 degrees but with different distances to each neighbouring plant.	The distance from one plant to all six neigh-boring plants is constant with an angle of a multiple of 60 degrees.	From one row to the neighbouring row always a shift of half the plant distance is applied.	The optimization is not done with respect to distances but to orientation. The plants positions describe a defined angle in the field.
This pattern is the simplest one and results a regular pattern in the field.	This allows each plant to get a maximum of resources like sun, soil and nutrients.	This allows the plant to have more space to the left and the right of the row and the use of bigger planting equipment.	Due to the sun's progress during a day it might be desirable to have the plants aligned to this progress. The resulting direction of the plants is different to the desired driving direction of the tractor. I.e. the driving direction might be better in terms of field border's direction.

Plot Planting The second category deals with the idea of creating small test fields to be able to compare different hybrids of plants. One of these small fields is called a plot. A standard sized plot owns a width of approximately 1.25m and a variable length of several meters. After harvest, the crops are classified by different parameters like robustness against environmental influences or yield. Usually a whole field is divided into a lot of these small areas, plots respectively. Each plot contains a different variety of seed to investigate the behaviour compared to varieties growing on other plots. Additionally to the preparations, which have to be done before seeding can start, a worker on the seeding implement has to take care of accurate triggering and take care that each plot gets its designated variety of seed. Allowing the planting system to take care of the triggering would allow the worker on the implement to better concentrate on loading the seeder correctly.

Figure 1. Plot Seeding Pattern



Only one pattern was defined in this category because the approach to align the plots in the field is always the same. The field containing the plots is separated into rows, rows are separated into segments and each segment itself contains a specific number of plots. By this definition the pattern to realize results from the direction of the row in "Seeding Direction" (Figure 1). Due to the fact that for example a sprayer driving in "Applicators Direction" (Figure 1) always works symmetrically to the left and to the right, it is desirable for the user to have plots below left and right side of the sprayer's boom while spraying. This constraint adds a start and an end segment to each row, whereas these segments contain only half the number of plots than a standard segment.

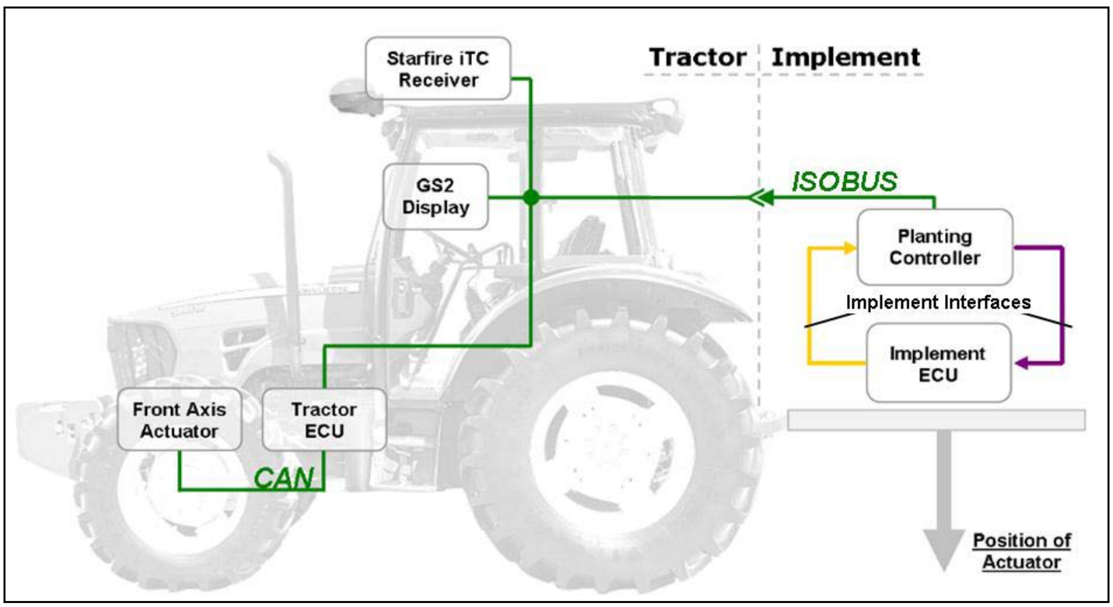
Objectives After collecting all necessary information and requirements regarding the pattern application the subsequent steps were defined as

- **System Development** With respect to the evaluated requirements the planting system had to be defined including hardware components and algorithms.
- **System Verification** As a fist step to test the developed system, a test environment had to be set-up to evaluate if on the one hand the desired patterns were created successfully and on the other hand if the pattern was created with the needed accuracy referring to the desired absolute positions of the plants.
- **System Test in the Field** To prove the concept of the pattern application in the field, an implement for planting operations had to be equipped with the developed system to test functionality and usability under field conditions.

SYSTEM DESIGN The general approach of the system's design is to have a generic implement controller interfacing either the implement ECU or if not available directly controls the implement specific interfaces. This implement controller should be compliant to the ISO 11783 standard [3] to be able to visualize process data as a Virtual Implement (VI) and support documentation using Task Controller functionality. The implement controller was meant to be applied as easily as possible on a connected implement and therefore only standard equipment for navigation and data processing was used. This includes the renunciation of any additional sensors than GPS. Figure 2 shows a system overview with the basic system components listed below.

- **StarFire iTC.** GPS receiver with differential John Deere mobile RTK [5] mounted on the roof of the tractor. The StarFire iTC is the only source for positional data acquisition. The possibility of multiple GPS receivers was not realized to keep the system more generic and affordable for possible customers.
- **GreenStar Display 2600.** The used controller is designed as an implement controller and has its own VI screen to be shown on the GreenStar Display 2600 [5]. All needed parameters for the pattern application can be set here. Furthermore ISO compliant documentation can be done on the display (with built-in Task Controller support)
- **Tractor ECU.** The tractor is equipped with JD AutoTrac[4] which allows precisely driven straight rows.
- **Planting Controller.** The planting controller is a standard John Deere controller, using a real-time operating system and provides interfaces for CAN Bus, IO, ADC and PWM. This gives the opportunity to control numerous implements by either interface their own ECU or their electric/hydraulic controls.

Figure 2. System Overview



User Interface The Planting Controller has its own ISO 11783 compliant Virtual Implement (VI) and Task Controller. These features allow to configure all needed pattern parameters and the documentation of the triggered positions.

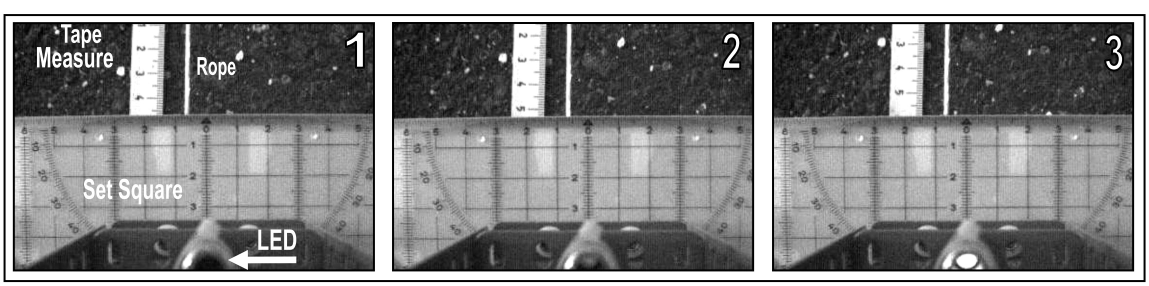
Algorithms The algorithms for the planting / plotting application are all running on the planting controller. The following assumptions and principles are the foundation of the derived and implemented pattern algorithms

- **Straight Rows.** Referring to the fact, that all patterns have a straight driven row in common, the calculation of each desired position in the field can be broken down to a distance calculation with an inter-plant distance and a parameter for an offset to be able to take a row-dependent shift into account.
- **Position Interpolation** Due to the fact that positional data from the GPS receiver is only sent with a rate of 5Hz, the positional data has to be extrapolated using the current speed and direction of the vehicle; assuming that speed and direction is constant between two positions. This provides the needed accuracy.
- **Vehicle Dimensions.** Due to the decision, to have only one GPS receiver onboard and not an additional one directly above the actuator, the positional data from the GPS receiver is recalculated regarding the system's dimensions. As a first step it is assumed, that the implement is mounted in-line and centered referring to the tractor's driving direction.
- **Actuator Delay.** Using implements of different functionality and manufacturers raises the question of how the different reaction times are taken into consideration. Currently the delay for an implement can be set on the VI screen, is re-calculated as a speed dependent distance and applied to the distance calculation.
- **Position Triggering.** Triggering of the desired positions is distance depended. Each time the actuator reaches a desired distance within a row, the actuator is triggered. Basis of all calculations is positional data within the AutoTrac system in StraightTrack mode. By definition a straight track is defined by a position 'A' in combination with a position 'B' or a heading. Whatever variant is used, position 'A' is always the initial planting position where all other triggered positions refer to.

SYSTEM TEST The system test is split up into two parts. The first goal to achieve within the tests was to prove how precisely the desired absolute positions can be triggered by the implement controller. As a subsequent step the controller's ability to interface an implement had to be proven as well as the application of the pattern in the field.

Accuracy Test First the accuracy of the system had to be determined as best as possible. This includes a test setup with the ability to eliminate or at least reduce distorting effects leading to assailable results. A mechanical actuator to mark positions on the ground would bring in actuator specific delays. To consider these delays is of course part of the software but to classify the control system this delay would bring in uncertainty. The applied speed during the test runs were 1kph and 2kph as these speeds are common if seeding or planting precisely in patterns.

Figure 3. High-Speed Camera Sequence



This uncertainty is reduced by using a high-speed camera (Pixelink™ PL-A741-E) on a mounting frame applied to a John Deere 6000 series tractor (Figure 4). The camera takes pictures with a speed of 100frames/s of the ground. A test track on blacktop was set up with multiple geo-referenced ground pins describing parallel straights rows. These rows were defined by thin, tight ropes. Furthermore the distances within these created rows were defined by tape-measures aligned to the tight ropes. A LED in front of the camera is switched on every time a desired position is reached. This is recorded by the camera and post-processed to evaluate the distance of triggering. The reference for a specific distance at a triggered position is defined as one side of an centered mounted set square. A consecutive row of pictures showing this procedure can be found in Figure 3.

Figure 4 – Tractor with High-Speed Vision System

The positions in the rows where determined by evaluating the data from the recorded video files. Referring to the functional principle of the application the targeted values during the measurements were only distance related: On the one hand the desired absolute distance, starting at a desired start position (i.e AutoTrac position 'A') and on the other hand the delta-distance between each position within a row. The standard deviation of the absolute position determined the reached accuracy whereas the delta-distance describes an indicator for a correct working pattern or possible accumulating offset errors. The diagrams in Figure 5 and Figure 6 are exemplary for the results after driving a row of 25m applying a 90 degrees pattern a with a plant distance of 0.5m resulting 50 triggered position each run.

Figure 5. Accuracy of Desired Distances

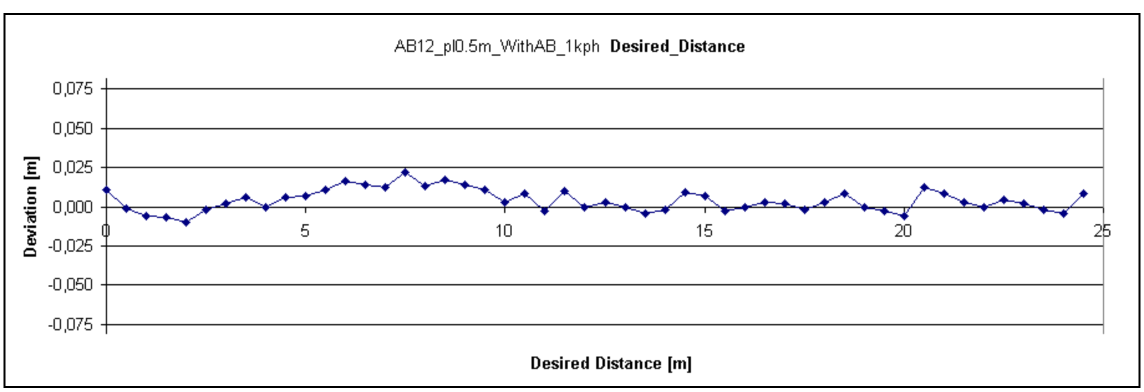
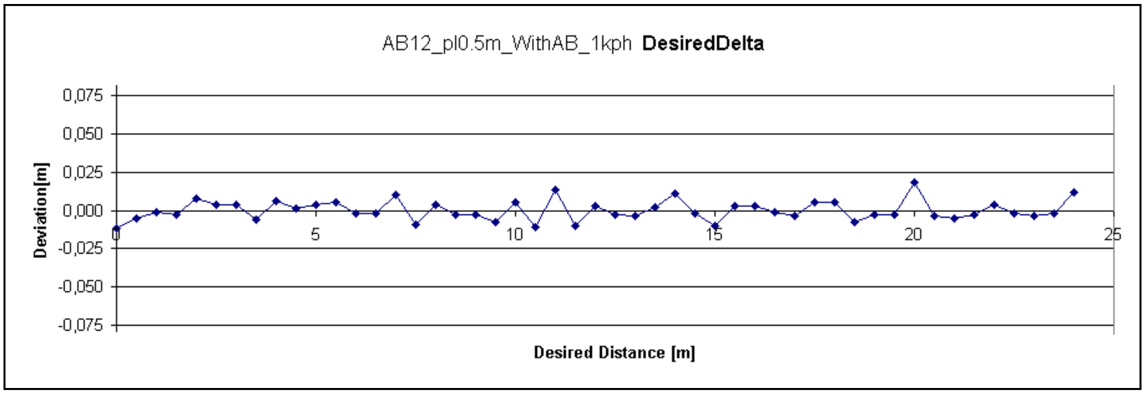


Figure 6. Deviation of Delta Distances



The overall results are split referring to the two speeds applied during the measurements. Mainly it can be stated, that the accuracy of the system applied on a test track with blacktop is just slightly worse compared to the specified precision of the only sensor within the system. The applied speed has an influence to the accuracy of the system: The average deviation increases with increasing speed as well as the standard deviation. Due to the fact that only 1kph and 2 kph were applied further tests have to be done to show the behaviour beyond these speeds. Summarized the results are shown in Table 2. As a reference the specified accuracy of the used mobile RTK system is listed in as well. No distinction was made regarding to the different patterns, because no significant differences were seen during the measurements revealing pattern dependent deviations. The number of the triggered positions resulting the final values for average deviation and standard deviation are 250 positions for 1kph and 500 positions applying 2kph.

Table 2. Results of Measurements – Absolute Accuracy

	Standard deviation 1σ	Standard deviation 2σ	Average Deviation
John Deere mobile RTK (specified signal accuracy [6],[7])	10mm	20mm	-
Pattern Application 1kph (measured accuracy)	12mm	24mm	4mm
Pattern Application 2kph (measured accuracy)	14mm	28mm	8mm

Field Test After finishing the tests regarding precision and patterns, the planting system was tested under field conditions. A 4000 series John Deere tractor was equipped with a plot seeder interfaced by the implement controller (Figure 7). All triggering of the seeding process, which had to be done manually before was now handled by this controller. After setting all parameters on the display in the cabin, the system was able to apply the desired pattern reliably in the field. Due to the fact that the precision was already determined using the high-speed camera on the test track, the reached accuracy was not determined again but only roughly verified by tape measures.

During the field tests no accuracy tests were made like it was done on the test track, but the previously mentioned aspect of field preparations was not necessary anymore and saved several hours of work. During the field tests the integrated ISO11783 Task

Controller was able to record process data of the planting controller. Unfortunately the current ISO 11783 standard does not support single plants. This circumstance made it necessary to work with simulated area specific data while applying single plant patterns. Only plot patterns for seeding plots are able to use the Task Controller functionality reliably.

Figure 7. Field Test Equipment – John Deere 4720 with Plot Seeder

CONCLUSION A system was set up to trigger position dependent planting operation for single plants and variety test plots. The system was designed using standard components for positional data acquisition and processing and working with a standardized user interface (ISO 11783 Virtual Implement) and documentation system (ISO 11783 Task Controller) [3].

It was shown that the pattern application is able to trigger pattern dependent planting operations with accuracy better than ± 3 cm by using only standard components without additional sensor systems. The results were verified on a test track using a high speed camera which turned out to work very well for this purpose. Afterwards the developed planting controller was successfully tested in the field by applying the controller on a standard plot seeder interfacing the controls of this implement. This replaced the former manual triggering and the pattern was realized precisely and reliably. Further tests have to be done to on the one hand show the usability of the system regarding additional implements for single plants and to prove the accuracy when applying higher speeds.

Finally it turned out that the current ISO 11783 Task Controller documentation mainly targets at applied rates (like mass/area) rather than single seed operations. The latter ones have typically no unit associated since they represent just a number (count) and a GPS position. Outside of proprietary solutions, these operations are not recordable using the current standardized system. Here more work and consideration needs to be invested to be able to support today's precision farming needs.

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