Steering of a seeding process with a multi-sensor system

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Keywords: GNSS/GPS, positioning, steering, machine control and guidance, Kalman filter, MEMS, sensor fusion

SUMMARY

Regular geometry of seeded plants can help the automation of cultivation processes like weed control. One case of application is the seeding of sugar beets. In this case the sugar beet planter is to provide an exact spacing in vertical and horizontal direction in order to make mechanical weed control possible. The main requirement for controlling the seeding process is the calculation of a precise position at every time step. The calculated position information is used in a feedback control loop for an electronically driven seeding mechanism. This paper shows the position calculation mechanism with a time synchronized multi sensor system. The system includes a highly accurate RTK-GPS sensor for position determination, an odometer for travelled distance and a MEMS gyroscope for the increase of availability and robustness of the orientation estimation. The fusion of the different signals is realized in a Kalman filter using the kinematic model of the seeding-machine. With the estimated position and orientation from the filter a dead-reckoning task can deliver the position at any time. All the calculations and measurements are implemented in an embedded control and monitoring system. This system contains a controller unit with a real-time operating system for time deterministic calculations and an FPGA for fast input output functions. Experiments with a rotating marker mounted instead of the seeding unit were used to verify the calculated positions and to determine the accuracy of the system. A position accuracy of less than 1cm standard deviation was reached.

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1. INTRODUCTION

In many Precision Farming applications automated technologies with steered or controlled machines are used. In most of these systems the actual position is an important measurement value. For precise vehicle guidance and machine control geo-referenced data with an accuracy of a few centimetres and a high availability are required.

The seeding of plants with the objective of high accurate placement of seed for later weed control like intra-row weeding is an example of an application. The controlled seed deposition allows to structure longitudinal and lateral rows in the field. The lateral rows enable intra-row weeding with a conventional hoeing machine, controlled rotor weeder or autonomous robotic weed control systems (Weis et al. 2008, Griepentrog et al. 2006, Slaughter et al. 2008).

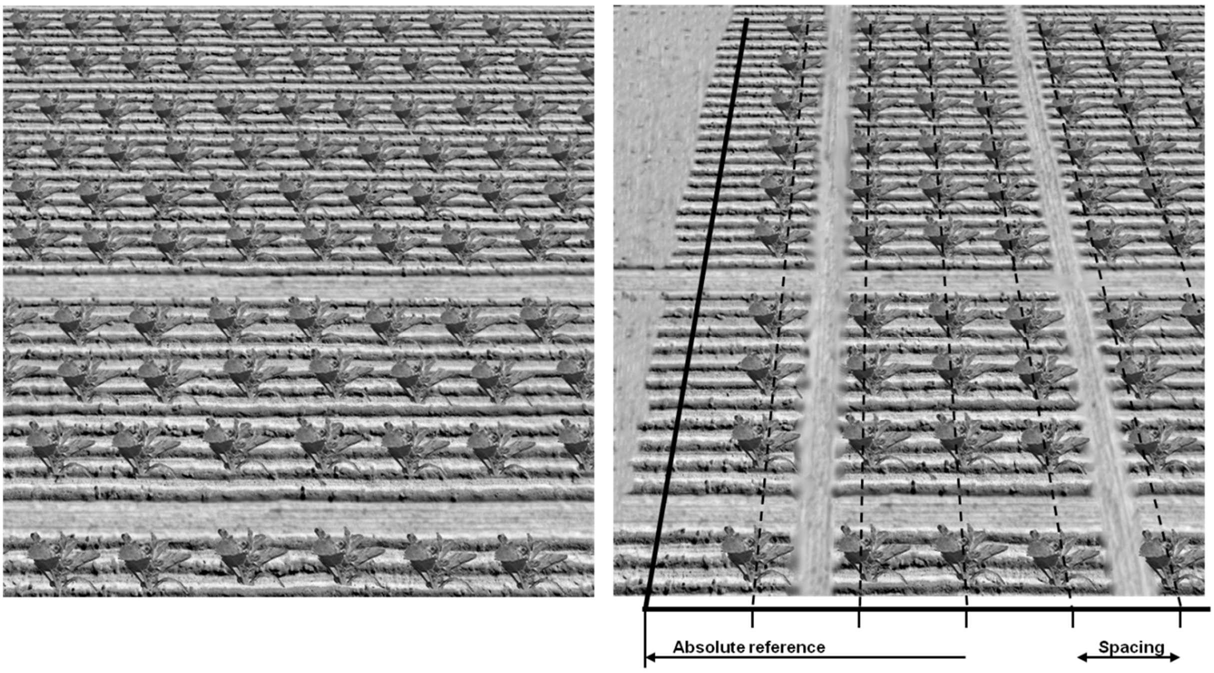

Fig. 1: Field with irregular and regular sugar beet plants (absolute reference, spacing)

The exact knowledge of each crop plant position makes it possible to locate individual plants at a later time. The result can be an accurate seed map for later use (Griepentrog et al. 2005). Phenotyping techniques with automated field robots can use the information from the seed map and the robot position to locate the plants for additional measuring like growth status or plant disease (Klose et al. 2009).

In this work the control system for a motor driven seeding machine for sugar beet is developed with the objective that the plant spacing and the plant position in each row can be defined. The seeding machine is replaced by a stepper motor driven rotating marker. The function is similar to the principle of a seeding machine like the Accord Monopill SE with the directly driven seeding heart by a variable speed electric gear motor. The set value of the controlled seeding process depends on the position and the orientation. It is also necessary that these parameters are available at real-time.

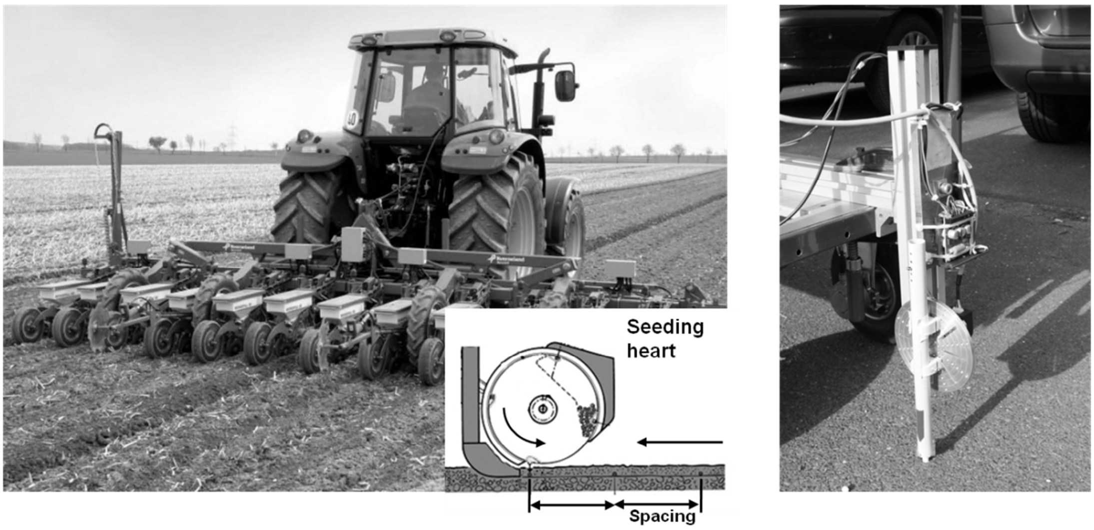

Fig. 2: Kverneland Monopill SE with seeding heart (Kverneland 2012), stepping motor driven rotating marker

The used hardware, the real-time implementation of the measurement process, the sensor fusion and the motion control are described below.

2. SYSTEM

The institute owns a test vehicle for use as a mobile testing platform, which can hold different sensors. The vehicle is a handcart with pneumatic tyres and contains a mounting system for setting up experiments and stable power supply with connectors for controllers, sensors, and actuators. The overall setup of the system is shown in figure 3.

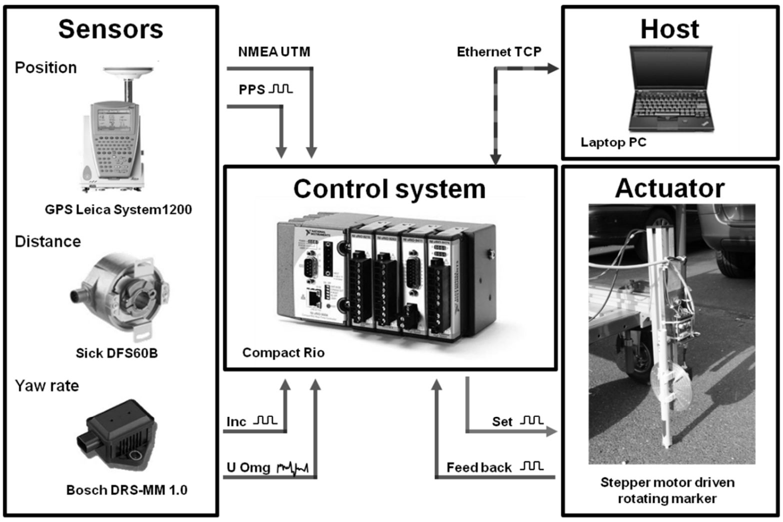

Fig. 3: Configuration of the mobile platform

The platform is equipped with a GPS-system, a travelled distance sensor (odometer), mems gyroscope (yaw rate sensor), the stepper motor driven rotating marker as actuator, a measurement controller and a laptop as host system. The advantage of using the yaw rate sensor and the odometer in addition to the GPS sensor is that the angular rotation and distance data is provided at high update rates and can provide the position estimation.

2.1 The Global Positioning System

The sensor for the position feedback in the form of a georeferenced global position used on the mobile platform is a Leica GPS1200 real-time Kinematic Global Positioning System (RTK GPS) receiver (Leica Geosystems 2010). The RTK GPS system requires a GPS base station located near the mobile platform. The reference station transmits correction data to the mobile rover using a radio modem. The maximum distance from the rover to the base is about 2km. The antenna of the GPS receiver is fixed above the front roll centre of the handcart. The GPS unit is a low frequency sensor and generates position data with an update rate of 10Hz. The raw data is transformed into the receiver in UTM coordinates. The coordinates are sent to the measurement and control unit via RS232 interface. The PPS output of the receiver is also connected to the measurement and control unit and is used to synchronise the controller clock with the GPS receiver clock and generates an event to trigger the position calculation. Due to the sufficient number of visible satellites and the geometry during the experiments the RMS values for the GPS position are about 1 cm horizontally and 2 cm vertically.

2.2 Odometer

The track measurement is realised by two odometers (DFS60B by Sick) mounted at the front wheels of the test vehicle. The DFS60 is a high-resolution incremental encoder in a small design and its resolution is 8192 lines per one cycle. In addition the sensor offers a reference signal for each revolution.

The incremental encoders are used to track the motion and to determine position and velocity. They employ two outputs called A and B, which are called quadrature outputs. These two output wave forms are 90 degrees out of phase. The signals are decoded to produce a count up pulse or a count down pulse. With the information of the signal states it is also possible to decode the direction.

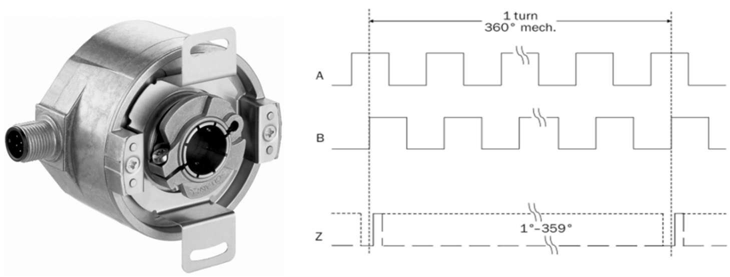

Fig. 4: Sick DFS60, quadratur encoder output (Sick 2012)

It is possible to decode the A B signal very fast so the encoder is a high frequency sensor and the signal is available nearly just in time. The precision of the distance travelled depends on the resolution of the encoder and the wheel diameter. Because the total distance is the sum of many single measured distances the constant deviations of the measurements are also added to a growing error. This type of sensors can only deliver a high accuracy over a short distance.

2.3 Yaw rate sensor

On the platform is an additional sensor to improve the orientation estimation. If the orientation is derived only from the GPS position, the estimated heading is less robust. The smaller the speed the less confident is the determined orientation. This is because the heading angle can only be calculated consecutively using the sequence of measured positions and if the distance of the positions is small the position error has a huge influence on the calculation. The applied sensor is a Micromechanical system (MEMS) device from Robert Bosch GmbH (Lutz et al. 1997). This sensor is used in automotive systems for applications like the Electronic Stability Program (ESP), navigation systems or roll over detection.

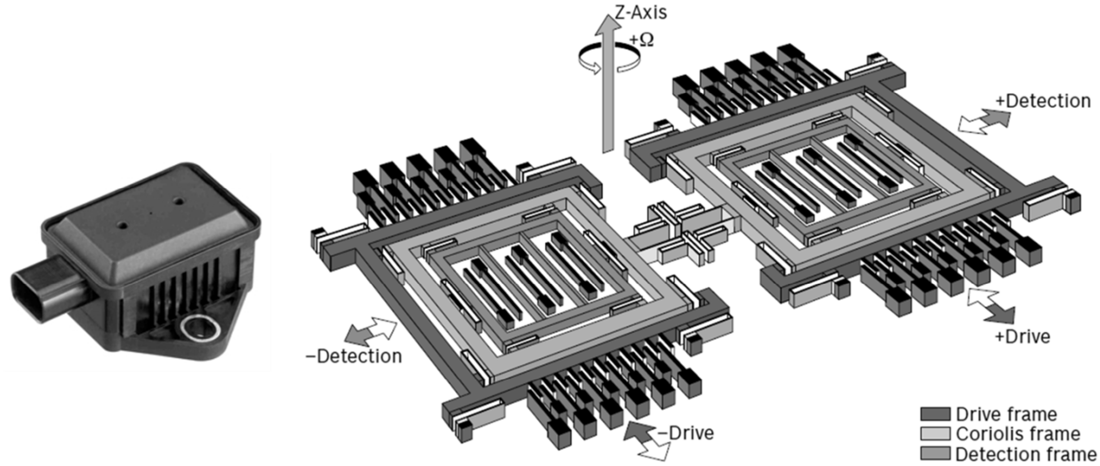

Fig. 5: Yaw rate sensor Bosch DRS-MM1 (Bosch 2012)

The DRS-MM1 yaw rate sensor consists of a capacitively driven silicon oscillator that is suspended by a few webs of material. In case an external rotary motion perpendicular to the axis of oscillation, the vibrating mass undergoes a deflection from its plane of vibration because of the Coriolis force. The resultant Coriolis acceleration is a measure of the yaw rate and is recorded capacitively. Internal temperature compensation with a linearization delivers a reliable analog current for the detected yaw rate. The sensor is trimmed for a 100 deg/s range and the sensitivity is 18 mV/deg/s.

2.4 Measurement and Control Hardware

The base of the hardware used for the measurement and control is the CompactRIO System from National Instruments. This is a rugged configurable control and monitoring system with an embedded controller, swappable industrial I/O modules and a reconfigurable field programmable gate array (FPGA). The embedded controller (cRio-9014) implements a real-time operating system (RTOS) allowing to execute deterministic control loops with update rates more than 1 kHz. It is also possible to manage multiple program tasks with different update rates and priorities. The FPGA (cRio-9104) contains 3 million configurable logic gates which provide many parallel processes in real-time with update rates up to 40MHz.

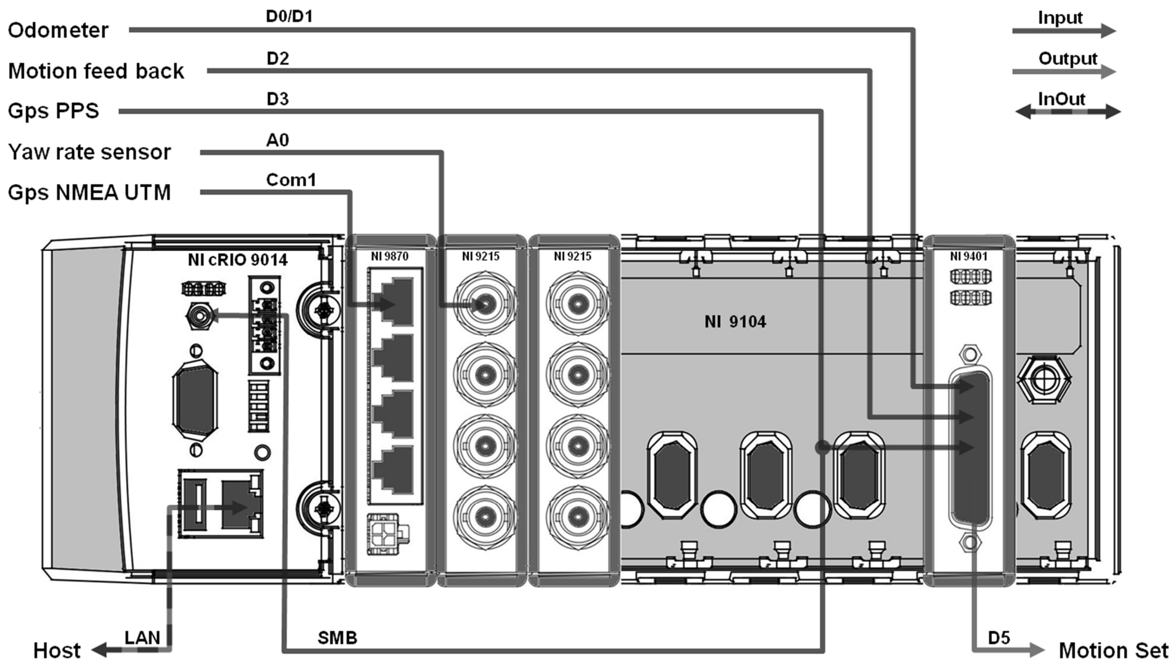

Fig. 6: Reconfigurable control and monitoring system CompactRIO

To digitise an analog sensor input a 16-bit digital analog converter I/O module (Ni 9215) with a sampling rate of 100 k-samples/s has been implemented. The digital communication is realised with a high speed bidirectional digital I/O module (Ni 9401) and a serial communication interface RS232 is also implemented with a dedicated module (Ni 9870). All modules communicate with the FPGA part of the system which provides parallel time deterministic capturing and output. For all non deterministic tasks there is a Windows PC (Laptop) as host system which is connected to the embedded controller via Ethernet. The host environment contains a user interface for operations like data logging, visualisation, and configuration. Figure 6 shows a connection diagram of the control system and all the used devices.

2.5 Programming environment

The software for the three main system parts which are host, embedded controller and FPGA was written in the graphical dataflow language LabVIEW. The graphical programming is performed by wiring together graphical icons on a diagram, which is then compiled directly to machine code. The wiring describes the flow of data between the nodes in the program. The different program steps and the dataflow are easy to understand within a LabVIEW diagram and the diagram can also represent a documentation of the program. The development system includes a project management which manages the communication between the different hard and software modules, the compiling procedure, the code transfer to the embedded controller and the reconfiguration of the FPGA.

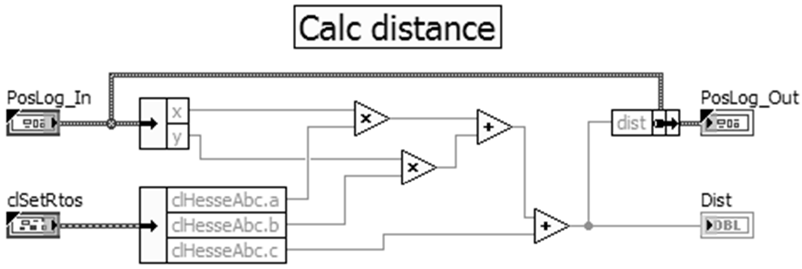

Fig. 7: LabVIEW graphical programming code

The real-time application for the embedded controller is also designed using graphical programming. With the LabVIEW Real-Time Module it is possible to instantiate multiple program tasks with different task priority. The environment allows the user divide the program into important parts like deterministic position calculation and less important parts like data visualization. In addition it is possible to optimize the timing of the real-time applications with in-depth tracing tools and download the compiled stand-alone application to the target.
The FPGA program is also designed using graphical programming. The code is automatically translated into the hardware description language (VHDL) and compiled into a hardware circuit realization used to configure the FPGA. With the LabVIEW FPGA development Module, it is possible to create custom I/O measurement and control hardware without low-level hardware description languages or hardware board-level design in a short time.
The user interface on the host PC is also part of the LabVIEW project. The data communication to the embedded controller via Ethernet is automatically managed. The main part of the human machine interface is a GIS application which is integrated using the dotNet Framework from Microsoft. It shows the actual position of the vehicle, the track and the seeding map.

Fig. 8: Host application with actual position, track and seeding positions

In several menus all system parameter are displayed and can be set by the operator. On the host system it is possible to log different system states with a sample rate up to 1 kHz. These log-files can be used for documentation (seeding positions) or later simulations and debugging.

3. Calculation process

The processing software on the Real-time system of the embedded controller is divided into a high priority task with a high sample rate (1 kHz) and a lower priority task with the sample rate of the GPS device (10 Hz). The low priority task is hardware triggered by the PPS pulse of the Leica GPS receiver and in this task a Kalman filter uses a combination of the GPS position and the additional sensor data to estimate position and orientation. The estimated results are transmitted at each PPS event to the high priority task which runs with a sampling rate of 1 kHz.

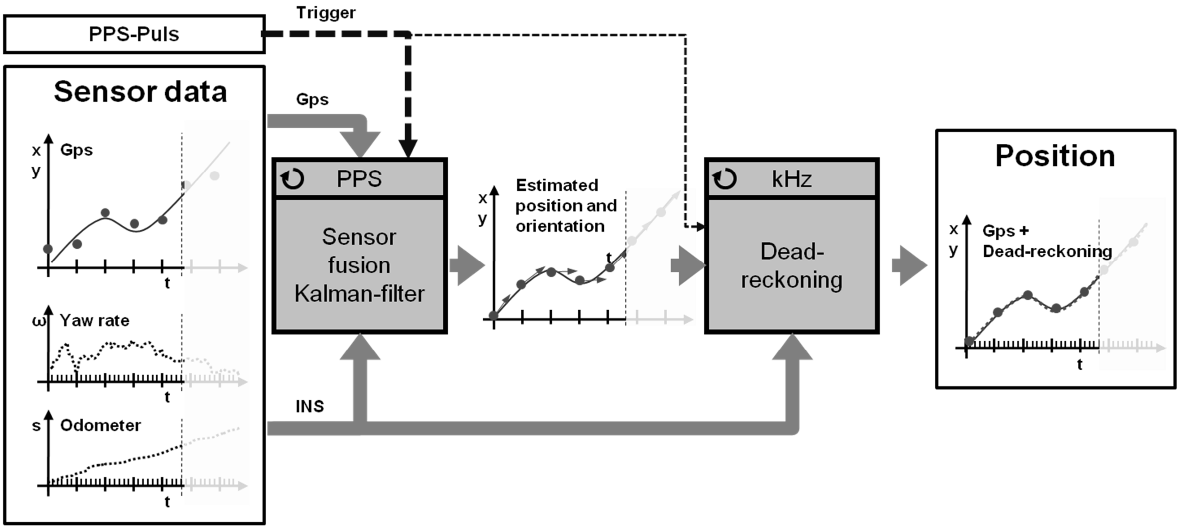

Fig. 9: Real-time calculation process

In the 1 kHz task the actual position and the set point values for the motion control are processed each cycle. Figure 9 gives an overview of the relationship of the real-time calculation process. The individual parts of the two tasks are described in the following.

3.1 Sensor fusion with Kalman filter

The core of the navigation loop is a Kalman filter which estimates the current position, velocity and orientation. A good overview of Kalman filters for localisation can be found in (Thrun 2005). The filter delivers an optimal estimation of the state of the mobile platform. The estimation depends on the sensor input with the related variances and the model description which represents the inertia of the mobile. The advantage of the Kalman filter concept is that the calculation can be done in real-time with low computational effort. The weighting of the measurement and disturbance allows a flexible adjusting of the system. The model contains the measurement vector with the elements of the GPS measurement xy, the yaw rate and the odometer value. The transition matrix describes the change of the state vector with the kinematic equations of the mobile platform in a plane. The discrete process model being used is shown in figure 10.

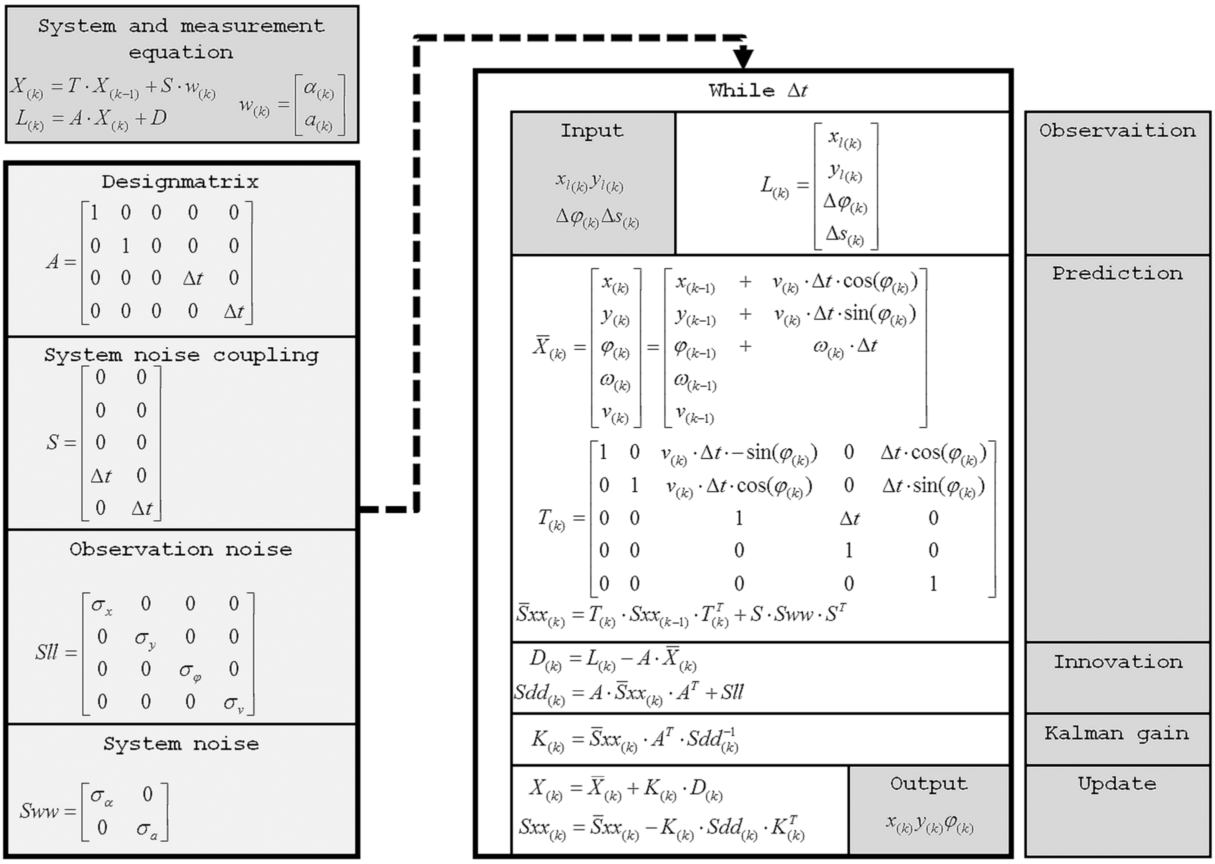

Fig. 10: Kalman filter cycle

The filter is triggered by the PPS pulse of the GPS device, reads the actual yaw rate, odometer distance, waits for the incoming GPS position and starts the filter calculation with the update. The frequency of this task depends on the sample rate of the GPS device, in our experiment this rate was 10 Hz. Each 100 ms the estimated states are transmitted to the dead-reckoning task. The accuracy of the Kalman filter estimation depends on the accuracy of the yaw rate, the odometer and the GPS readings. The better the accuracy of these sensors the better is the accuracy of the estimated state vector.

3.2 Dead-reckoning

The dead-reckoning task calculates the current position and orientation when the GPS position information is not available. In our system this is necessary because the measurement rate of the GPS is only 10 Hz. The dead-reckoning calculation is done every millisecond and is 100 times faster than the Kalman-filter task. The dead-reckoning is updated every 100 ms by the Kalman filter. The event for the update process is also the PPS-pulse of the GPS device. The update states are exactly 100 ms old and this latency time range has to be filled. The procedures of the main program parts show the following figure as Nassi-Shneiderman-Diagram (DIN 66261).

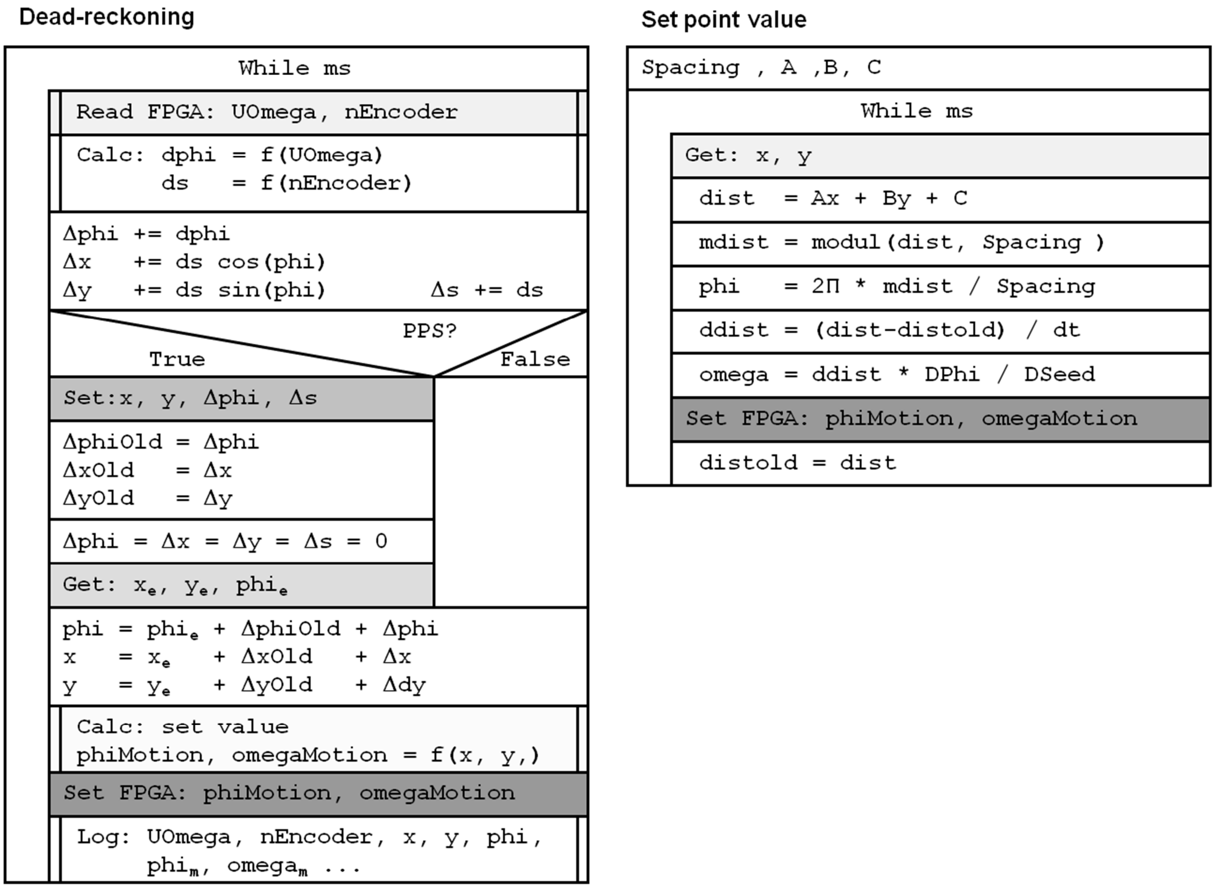

Fig. 11: Nassi-Shneiderman-Diagram of the dead-reckoning task

The calculation of the x, y position and the orientation happens at each loop iteration with a frequency of 1 kHz. After the position is calculated the set value for the motion control is calculated and transmitted to the motion controller which is processed on the FPGA device of the control system. The set value depends on the distance to the absolute reference, the field border shown in figure 1. The reference line is defined by two measured fix points P1, P2. In the system this line is described in the Hesse normal form with the constant coefficients A, B and C.

$$P1, P2 \Rightarrow A \cdot x + B \cdot y + C = 0$$
$$dist_{(k)} = A \cdot x_{(k)} + B \cdot y_{(k)} + C$$

With the known coefficients it is possible to insert the actual position in equation and the result is the actual distance to the reference line. The actual distance and the desired spacing delivers the set angle for the Motion control.

3.3 Motion control

The process controller is implemented as PI-controller with speed feed forward and the motor angle feedback. The closed loop is implemented in the FPGA part and it is possible to apply multiple control systems in real parallel processing mode. The loops receive the same set values from the dead-reckoning RTOS task and measure the individual feedback angle from the related motor. The cycle time of the controller loop can be more than 10 kHz and is ten times faster than the dead-reckoning task.

A controller with a feed forward control has the advantage that the set value can be followed very accurately at a high speed. The integral part of the controller can compensate constant disturbances. The feed forward and the integral part are limited to prevent an overload of the motor (Föllinger et al. 1994).

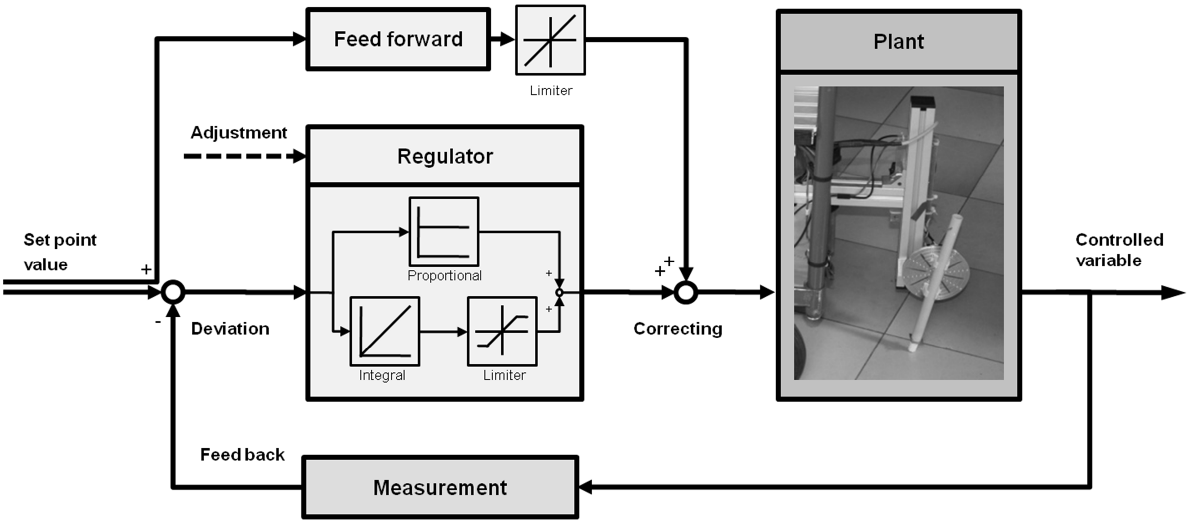

Fig. 12: Action diagram of the closed loop control

With the adjusters of the limits, integral and proportional factors the optimal control adjustment could be done on the host system.

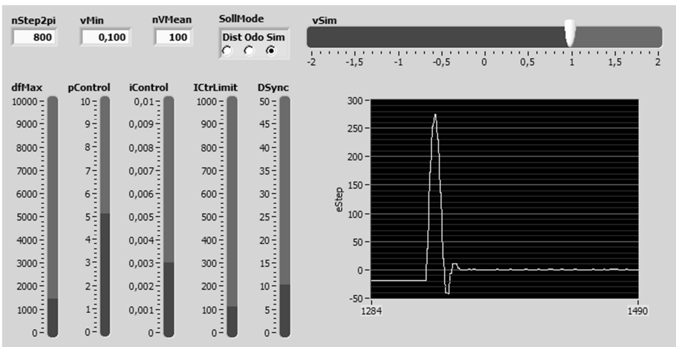

Fig. 13: Adjustment and testing of the closed loop control in the host application

The performance of the control loop and the motor can be tested using a step function. The step response of the system is shown in a graph and can be evaluated just in time. This procedure is known as hardware in the loop (HIL) testing.

4. Test and results

The system with a rotating marker instead of the seeding unit was tested on a parking area near the institute. The reference station was mounted on the roof of the institute with a distance of about 500m to the parking area. Five movements forward and backward were made. The speed of the platform was about 1m/s and the length of the individual tracks was 18m. The spacing for the individual seeding position was 1m. The following graphic shows the seeding map with the motion path of the platform received by the measurement system in UTM coordinates.

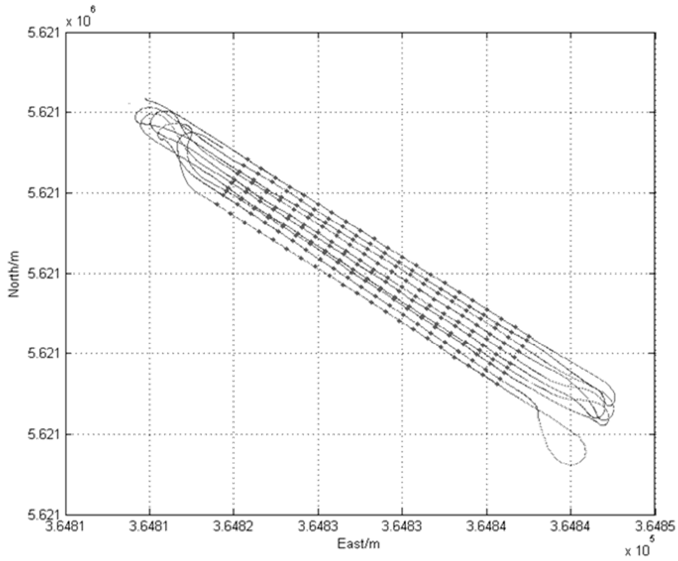

Fig. 14: Seeding map with motion path in UTM coordinates

180 points are made by the rotating marker and the points have a diameter of about 5mm. All the points have been surveyed with a Leica total station and prism pole in a local coordinate system. The accuracy of this measurement is assumed to be less than 2mm.

The position deviation from each point derives from the distance to the reference line and the preset spacing. The distance divided by the spacing should be an integer value if a fractional part exists this is the displacement of the individual point or seeding position.

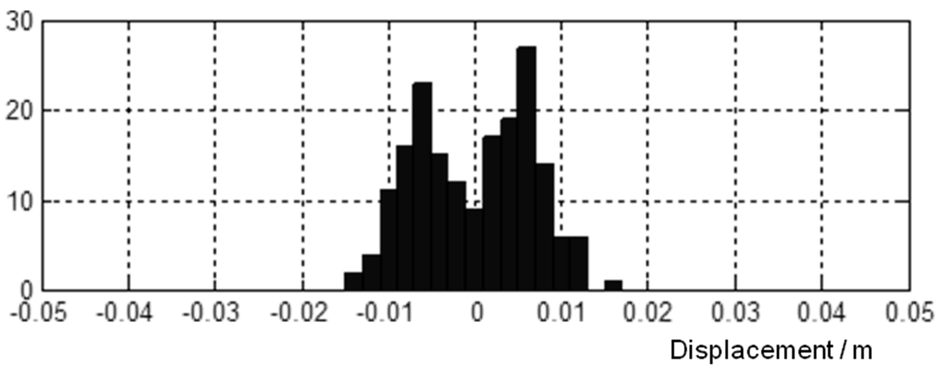

Fig. 15: Histogram of the displacement

The histogram of the deviations shown in figure 15 contains two maxima. This effect is because of the forward and backward track direction. The distance from the GPS antenna to the actor is not well determined and this results in an eccentricity error which depends on the track direction. However, even with this inaccuracy a standard deviation less than 1cm was reached.

5. CONCLUSIONS AND OUTLOOK

The hard and software concept using the National Instruments development environment with the possibility of the easy handling of the real-time processing tasks and the FPGA design gives an opportunity to develop complex and fast measurement and control application with reasonable costs. This includes the induction period for the development environment, planning, assembly and commissioning to maintenance. The experiment shows that it is possible to process the position with a high accuracy just in time with a reliable RTK-GPS position and low cost inertial sensors. One requirement for this accuracy is the fusion of different sensors with various sampling rates and errors and the processing in a time deterministic system. In the experiment a standard deviation of less than 1cm was reached, this resolution is good enough for seeding maps and allows for example to seed sugar beets in a regular arrangement so that it is possible to create lateral rows in the field for the weed control like intra-row weeding.

The development system gives the opportunity to add sensors like tilt sensors or to calculate the yaw rate by the differential odometer instead of the MEMS gyroscope.

Another application of the real-time system can also be used to take precise georeferenced photos of defined objects with orientation. These photos could be taken in motion and it is not necessary to stop.

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BIOGRAPHICAL NOTES

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