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Real-time Process Control for a Sensor Based Fertilizer Application System based on Multi-sensor Data Fusion

Within the DFG project "Integrated System Precision Farming Dürnast (IKB Dürnast)" the real-time sensor-approach with map overlay for intensive nitrogen fertilizer application was investigated in detail and simulated in a laboratory environment. The main focus was to compile data from different information sources and from sensors in real-time operation, to ensure an integrated specification and development process for an efficient and goal-oriented implementation. Distributed electronic systems were purposefully used, which will be available with standardized Agricultural Bus-Systems (ISO 11783, DIN 9684) in the future.

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Keywords

Real-time approach with map overlay, multisensor, data fusion

Three different system approaches determine the process control in mobile application systems for spatially variable fertilization. These are „mapping systems" ("mapping approach"), real-time sensor-actuator systems („sensor approach") or the combination of both ("Real-time approach with map overlay"). Mapping approach and sensor approach have disadvantages depending on the system, however the „Real-time approach with map overlay" may overcome the disadvantages of both. In principle, the basic idea of this approach is to guide a process or system, here plants and their surroundings, to an ecological and economic optimum. This requires information about the current state of the process and its inputs, i.e. "precision farming maps" and on-line sensor technology process data. The possibility for intervention on the process is fertilization. Thereby, the application set point is derived by expert knowledge and the input information at hand. Documentation completes the procedure.

Methods

Conventional control system methods require that input information originate from a common feature space and have a numeric format. This is not given for the described task. Thus some kind of intelligent process control is needed. A multisensor data fusion approach offers a solution with corresponding methodology and adapted terminology.

Basically, an integrated theoretical framework should possess different levels of abstraction and should allow a top down decomposition of requirements as well as a following structured system design.

A functional model should describe at the highest abstraction level what analysis functions or processes need to be performed. While a process model describes at a high level of abstraction how this analysis is accomplished. Based on these abstract views of demands, requirements and problem-solving paradigm, system architecture (high level abstraction of hardware - software implementation) has to be designed. Established and appropriate systems engineering methods have to be applied for further transformation of this system architecture into a concrete technical implementation by hardware and software.

Functional Model

A state of the art functional model for data was specified by the Joint Directors of Laboratories (JDL) and was revised by [1] as "Revised JDL data fusion model". This model differentiates five processing levels on the basis of types of estimation process, which roughly correspond to the types of entity for which state is estimated: :

- Level 0 Processing - Sub-Object Assessment
- Level 1 Processing - Object Assessment
- Level 2 Processing - Situation Assessment
- Level 3 Processing - Impact Assessment
- Level 4 Processing - Process Refinement

From a functional point of view the „Real-time approach with map overlay" can be completely specified according to the revised JDL data fusion model, since the bottom line of the "Real-time approach with map overlay" is a comprehensive situation assessment, i.e. an assessment of current on-line sensor technology measurements with context-sensitive interpretation. The authors described and explained it in [2] comprehensively.

Process Model

Based on the results of the functional model and by the means of an appropriate process model a suitable problem solving paradigm can be derived. A process model proposal according to [3] fits particularly well. This intuitive process model of the data fusion process leads to the identification of 15 classes of fusion problems and a taxonomy of 16 canonical problem-solving forms (index: I - XVI). There exists a well-defined relationship between the five-level functional fusion model and the 15 classes of fusion problems as well as a definite relationship between these classes and the canonical problem-solving forms. Therefore, this process model offers a straightforward approach for appropriate algorithm selection and is described partly in the following section. The analysis of existing knowledge classes for the real-time approach with map overlay results in:

- The new plant and soil attributes are short-term declarative knowledge.
- History of current situation on the partfield like location of (just) applied fertilizer, state of tractor-implement combination and weather are medium-term declarative knowledge.
- Knowledge of yield and soil maps and static domain constraints due to environmental protection or topography represent specific long-term declarative knowledge.
- A relationship/procedure for crop production and agricultural engineering assessment in order to derive application set point and achieve sufficient reaction time for application action represents explicit procedural knowledge.

Because this task requires the composition among short-, medium-, and long-term declarative knowledge and explicit procedural knowledge, the "Real-time approach with map overlay" algorithm represents a fusion class 15 task according to Antony's taxonomy of 15 fusion classes. The simplest problem-solving approach, which is context sensitive and meets the requirements is a rigid, single level-of-abstraction, model-based control structure. Since this approach is fundamentally a data-driven task, a generation-based algorithm is most appropriate. Consequently, the problem-solving paradigm represents a "canonical form IX" - approach. A typical representative for this approach is a conventional expert system with its forward-inference production rule paradigm.

System architecture

One conceivable implementation of the functional specification and the process model is a distributed sensor network (short term knowledge) and a central fusion node with medium-term and long-term declarative and procedural knowledge. Unfortunately, a straightforward transformation into a system architecture based on Agricultural BUS-systems (ISO 11783, DIN 9684) is not possible yet. At the moment, site specific crop management is only specified in the context of the „mapping approach" in these standards. Although the integration of online sensor technology experienced progress within the project duration, to the superposition with „overlay maps" no attention has been paid. However, the proposed definition of an "in-field controller" [4] allows an ISO 11783/DIN 9684 compliant implementation of sophisticated multisensor data fusion techniques. This "in-field controller" is the implementation of the above defined central fusion node. By the means of the integrated expert system, data of on-line sensor technology (vegetation index: REIP) and data of "precision farming maps" (historic yield, EM38, soil draft force, applied fertilizer rates of the same year), originating from the Farm Management Information System (FMIS), and environmental protection restrictions could be fused in real-time in the field.

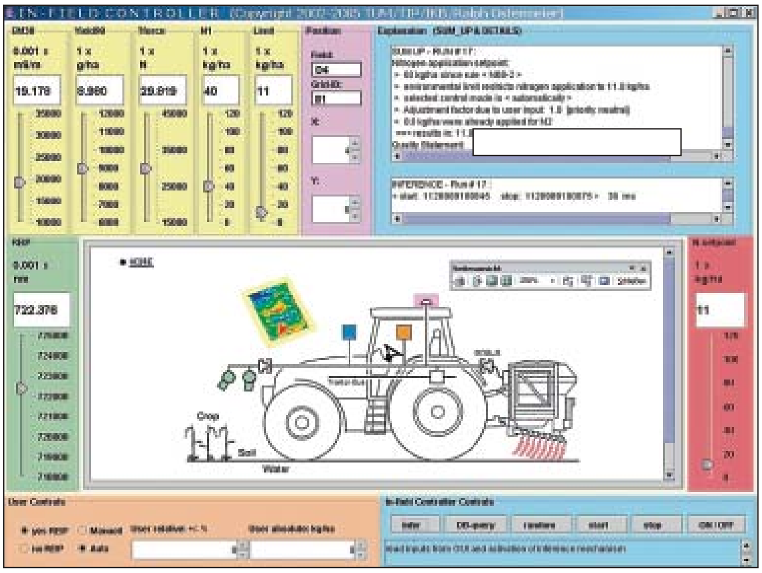

Fig. 1: Graphical user Interface of simulation

Simulation

Basic element of the simulation was the implementation of the expert system [5]. For this the hybrid expert system shell JESS (Java Expert System Shell) was selected for implementing the rule sets. Java was used for the graphical user interface (GUI) (*Fig. 1*) and to simulate the whole process environment. Parts of the knowledge acquisition were conducted in close cooperation with another IKB subproject [6]. The basic real-time capability for process control was demonstrated by measured typical and maximum processing times for one fusion and decision cycle of 10 ms and 60 ms on a 32-bit processor hardware (Intel Pentium III Mobile, 1 GHz) and a Microsoft Windows 2000 or XP operating system.

Outlook

Generally, a need for further research about the discussed topics can be identified. Especially the derivation of approaches to measure and to assess the performance of real-time process controls for mobile application systems based on multisensor data fusion should be pursued. The extension of this monovariable to a multivariable process control would be of a special basic research interest. A link to a more application-oriented research approach would be the integration of the proposed solution into practical application in order to achieve a possible experimental verification and validation.

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