

Evaluation and Modelling of a Standard Based Spatial Data Infrastructure for Precision Farming

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ABSTRACT

Geospatial information is becoming available increasingly in digital representations and can be created and consumed with the help of various different devices and services. Due to the increasing application of precision farming techniques the importance of spatial information and their implementation has become a key issue in operation planning and application in agriculture. Within the ICT-agri funded project GeoWebAgri present precision farming workflows for geo-data handling and data exchange have been analysed.

User groups in the precision farming domain, consisting of heterogeneous users like farmers and many others, have identified the benefits of the idea of precision agriculture. Nevertheless the current usage of those techniques is still inhibited by non-flexible, restricted and hard to use systems. Identified by a survey, the concept of a Spatial Data Infrastructure for Precision Farming applications (SDI-PF) was developed to particularly overcome the problems of geodata handling, because present Farm Management Information Systems (FMIS) and precision farming tools fulfil the needs only partly. The information-intensive, location-related tasks of precision farming were analysed and decomposed. Following the concept of Model Driven Architecture (MDA) a conceptual model was developed using the Profile for GML application schema of the Unified Modelling Language (UML). The derived physical models can be used to exchange PF data in an infrastructure, based on a server-client communication, driven by web-services and the standards from the Open Geospatial Consortium (OGC) and International Standardization Organization (ISO). The approach was tested by modelling an exemplary application of precision weed control and made a positive outlook for the integration of tailored services into existing task controlling, as well as maintaining interoperability with ICT-infrastructures of close-by domains.

Keywords: Precision farming, Spatial data infrastructure, Unified modelling language, Geodata, FMIS, ICT-infrastructure, Germany

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1. INTRODUCTION

The ICT-AGRI founded project “GeoWebAgri - Geospatial ICT infrastructure for agricultural machines and FMIS in planning and operation of precision farming” explored and identified the needs and nowadays' gaps for spatial data treatment in precision farming. A concept of a tailored spatial data infrastructure for precision farming (SDI-PF) was developed, necessary components evaluated and prototypic implemented for certain use cases. Current machines and products in modern agriculture are mainly developed from the technological point of view. Unfortunately geodata handling played a minor role for many years. With the increasing importance of precision agriculture techniques, the awareness grew concerning the location of field operations and their planning. Spatial data sets from different domains with high relevance for field applications are already available. Decentralized data storage as well as domain specific knowledge has to be incorporated into field operation and planning to maximize the benefit from such techniques.

Regarding the increasing importance of spatial information in agriculture, the ERA-NET ICT-agri project GeoWebAgri identified the weaknesses of spatial data handling and developed ideas for improvements. Whilst geospatial information is necessary for spatial decision support at a precise agricultural level, the users often face significant manual efforts to handle the geospatial data.

A systematic analysis of the SDI-PF was done, identifying its components for the agricultural domain. Furthermore their interactions have been modelled as use cases, representing an application within the complex system. The use cases create the foundation for the analysis concerning the exchange of spatial data, focussing on the reduction of negative effects on the environment caused by agricultural activity, utilizing a spatial ICT-infrastructure tailored for precision farming.

The remainder of the paper is organized as follows: First, the importance of spatial data in nowadays' agricultural practice is evaluated. The results of a survey, a theoretical analysis of the SDI-PF components and UML models for specific use cases are presented. While the survey and the theoretical analysis consider the SDI-PF in the wide range of agricultural applications, the paper focusses on a weed control use case in the results. The discussion summarizes the potential of the analysed infrastructure and shows additional fields of applications.

2. EVALUATION OF SDI-PF COMPONENTS**2.1 Identifying User Requirements**

To identify the users' requirements a questionnaire and a case-study were set up. The questionnaire's objective was to identify a minimum set of user requirements as background for the formal modelling in the use case description. 21 questions were asked in an online survey system. The survey was spread by newsletter, web pages and print media to reach a wide range of agricultural experts.

C0107

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Sustainable Agriculture through ICT innovation

2.2 Evaluation of SDI-PF Components for Common Use Cases

There is a need for the description and implementation of common use cases in the agricultural domain. A collaboration platform was created during the EU agriXchange project (cf. <http://www.agriexchange.eu>) to provide users and providers with non-formal use case descriptions, interfaces, standards and implementation samples. There is a significant overlap of use cases and appropriate components already hosted at the agriXchange platform with those of the GeoWebAgri project. Use cases like 'Request parcel boundaries' are a common task and are also part of the use case 'Precision weed control' analyzed in this paper. The implementation of such use cases can be organized in a SDI-PF. The main components of an SDI-PF are PF users and PF data. The connection between these components consists of the access network, the policy and standards (Rajabifard et al., 2002). These components can be considered to be intermediate entities, describing the data flow, formats and usage restrictions. The definition of the components is strongly linked to the user groups. In precision agriculture these include: farmers, farming machines, scientists, agricultural consultants, public authorities, companies and manufacturers. Every group can be data provider and data consumer. All groups are dealing with data sets, which might be relevant for other users, too. Not only the creation of spatial data, but also the processing can result in valuable re-usable geodata. Common examples are application maps, created by manifold sources and charting a field-specific dataset, documenting one influence to the yield, and by this, a relevant factor for post-analysis. Barriers between systems, existing in the form of diversified data formats, technologies, software and hardware boundaries, need to be addressed. The users' and systems' interactions and data exchange can be unified with standardised interfaces.

2.3 Evaluation of Standardized Modelling Approaches for SDI-PF Components

The user requirements and appropriate use cases for integration into the SDI-PF were analysed. In order to model descriptions of data applications, systems and users different modelling approaches exist. During the evaluation it was figured out, that a formal, logical modelling with the use of a Conceptual Modelling Language (CML, e.g. UML) is the most appropriate solution to keep interoperability on the model level. As part of the SDI policy there have to be strict rules (cf. ISO 19109) to derive the physical model of choice (here: GML Application schema) from the logical model. It is possible to only use a subset of a CML, in the case of GML models there exists an UML Profile for GML schema. In contrast to this there have been several, mostly national approaches to model agricultural data in a standardised way (e.g. agroXML). Nevertheless most of these models rely on a specific representation (e.g. XML) and are lacking a logical model in UML. UML is a de-jure and de-facto standard for the construction, documentation and visualization of characteristics and relationships of objects and processes. The used UML model types as they are presented here are Package diagram and Use-Case diagram.

Package diagram In order to give an overview about a complex system, package diagrams are used. By splitting a complex issue into packages, context information at

C0107

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Sustainable Agriculture through ICT innovation

different layers of abstraction can be shown. Relationships between the packages are expressed by arrows.

Use case diagram The use case diagram is a special view on the actors and their interactions with the system. Depending on the level of detail, a use case diagram can contain different layers. Its objective is the illustration of interactions of actors and system components, such that necessary interfaces can be identified. User groups and system limits are defined as well, as are interactions between different users.

3. RESULTS

3.1 User's Requirements

The online questionnaire identified the user's needs concerning the development of precision farming. Farmers having experience with precision farming experienced problems with the incoherence of data between different systems. An increased usability and interoperability of the components is needed. The users responded, that they are not willing to spend more than three minutes in the field for the terminal, the GPS, the software or other preparation related to the site specific application. The importance of applicable precision farming technologies was rated. Farmers are favouring the precision farming techniques auto steering and automatic boom section control. The overall of the ratings of field applications were similar and none substantially different. The acceptance of precision farming technologies is highly dependent on their usability. The system components on a farm, ranging from FMIS to terminal software and implement control, have therefore to be interoperable and easy to use. This requires a high degree of automation for the data exchange, since the data sets and processing facilities can be distributed over different systems, which might be located outside of the farm.

3.2 Realization of User's Requirements in ICT-Infrastructure

3.2.1 Client-server architecture

The user-groups concerned with precision farming techniques and data reside in different locations, equipped with individual IT-solutions. Data exchange has to be organized in a location and client independent way. A client-server-architecture can resolve the access from nearly everywhere by the use of networks. Common protocols ensure seamless interaction of all clients.

3.2.2. Service oriented architecture

The interoperability of a distributed infrastructure is driven by a service oriented architecture (Murakami et al., 2007). Web services at servers enable machine-to-machine-communication with clients. Services support the flexibility needed for the manifold cases in the domain of agriculture (Nash et al., 2010).

C0107

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Sustainable Agriculture through ICT innovation

3.2.3 Standards-based architecture

The use case study identified preferred standards for the data exchange. Besides standards of the World Wide Web consortium (W3C), like XML and FTP, there are also standards mentioned, which were developed for spatial information modelling and exchange. The most important standards are WMS (Web Map Service), WFS (Web Feature Service) and GML (Geographic Markup Language). Originally they were developed by the OGC, later they were integrated into the spatial family of standards of the ISO (191XX-series).

3.3 UML Modelling and Description of SDI-PF Components

The spraying task consists of a defined area (field), a machine (tractor and sprayer) with a task controller and network connected servers maintaining and providing (geo-)data. By using the task controller (TC) on the tractor, which was equipped with a sprayer, a weed control application should be applied.

Initially, data of the field boundaries were loaded from a server at University of Hohenheim, which provided a GML-encoded description of the geometries representing the boundaries of the fields. These were rendered and displayed by the TC. For a better orientation, the data set was overlaid with an aerial image of the region, requested from a WMS server at MTT. The terminal connected to a weather server via ftp every three hours and downloaded the latest weather forecast. The TC warns, if precipitation risk is above a defined threshold. The TC requests two further WFS of the server at University of Hohenheim: one with flood risk geometries and another with groundwater borders. The response is displayed together with the aerial image and the field borders. All required data was cached at the TC and used during the operation.

An application map for the spraying task was computed on the TC, defining spraying areas (inside field boundaries) and non-spraying (inside flood risk or groundwater boundaries) areas. The interaction between the different components is shown in the use case diagram in figure 1.

As described above, the use case has been implemented with the help of already existing services, not all of them are inter-operable in the proposed way. In addition to that, not all services are belonging to the agricultural domain (e.g. weather, ground water) and have to be modelled by experts of that specific domain. There are already existing initiatives which aim to serve domain-specific geodata in SDI's based on OGC web services. Therefore the system of services was decomposed and logical models concerning the described use case were considered: GeoWebAgri Model - Field Operation, Crop, etc.; Farm Management Model - Planning, Compliance; INSPIRE (<http://inspire.ec.europa.eu/draft-schemas>) - Groundwater; WXXM Weather Information Exchange Model (<http://www.wxsm.aero>) - Weather Forecast; ISO 28258 (<http://schema.isric.org/sml>) - Soil. The core GeoWebAgri model would benefit from a re-engineering of already existing agroXML core schemas, focusing on relevant entities necessary for precision farming field operations. Farm Management may be a separate package including Planning and Compliance. The remaining packages from outside the agricultural domain will be reused as needed and imported. An overview about the decomposed system shows figure 2.

C0107

J. Wiebensohn, M. Jackenkroll. "Evaluation and Modelling of a Standard Based Spatial Data Infrastructure for Precision Farming". EFITA-WCCA-CIGR Conference "Sustainable Agriculture through ICT Innovation", Torino, Italy, 24-27 June 2013.

Sustainable Agriculture through ICT innovation

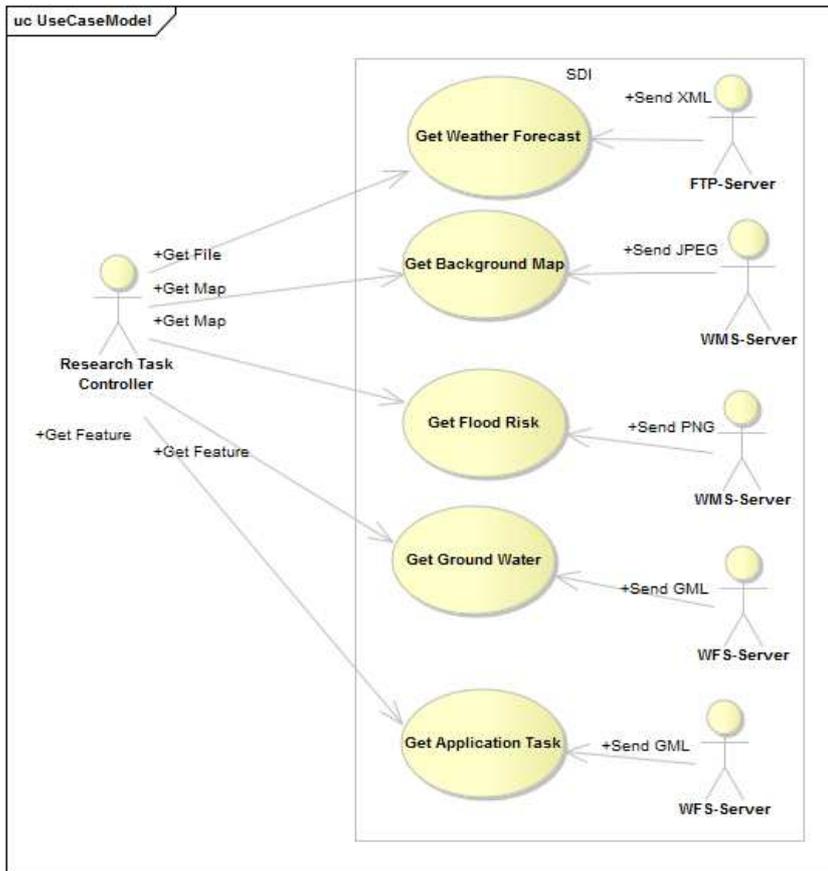


Figure 1: Simple UML use case diagram showing actors and operations

4. DISCUSSION

The survey of the GeoWebAgri project presents the importance of spatial data in agriculture as well as the user requirements for usability improvements, requiring a flexible ICT-infrastructure. The chosen use case “herbicide application” was analysed in detail, since it was identified to be an important precision farming technique from the questionnaire. Users as well as data sources were modelled in detail for the transfer from theory into the field. The analysed use case describes a basic application, which benefits from the GeoWebAgri infrastructure by the open and flexible architecture for integrating more information into the operation processing for a more effective and easy field work. The UML diagram is an appropriate tool to model the technical development of standard field applications. For the individual case, users, sources, objects and communication details were identified. Even complex ICT-infrastructures can be planned, set up and analyzed this way.

A next step for integration of spatial information into machines and software for precision farming applications would be the integration of agricultural topics into domain specific application schemas for GML according to ISO 19109. The benefit of such schemas is a unified semantic description of the geodata. This semantics can then

C0107

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Sustainable Agriculture through ICT innovation

be interpreted automatically by SDI components. The retrieval and interpretation of geodata in the agricultural context is thereby improved. Such schemas support the creation of new precision farming applications, and make the geodata sets reusable in multiple contexts.

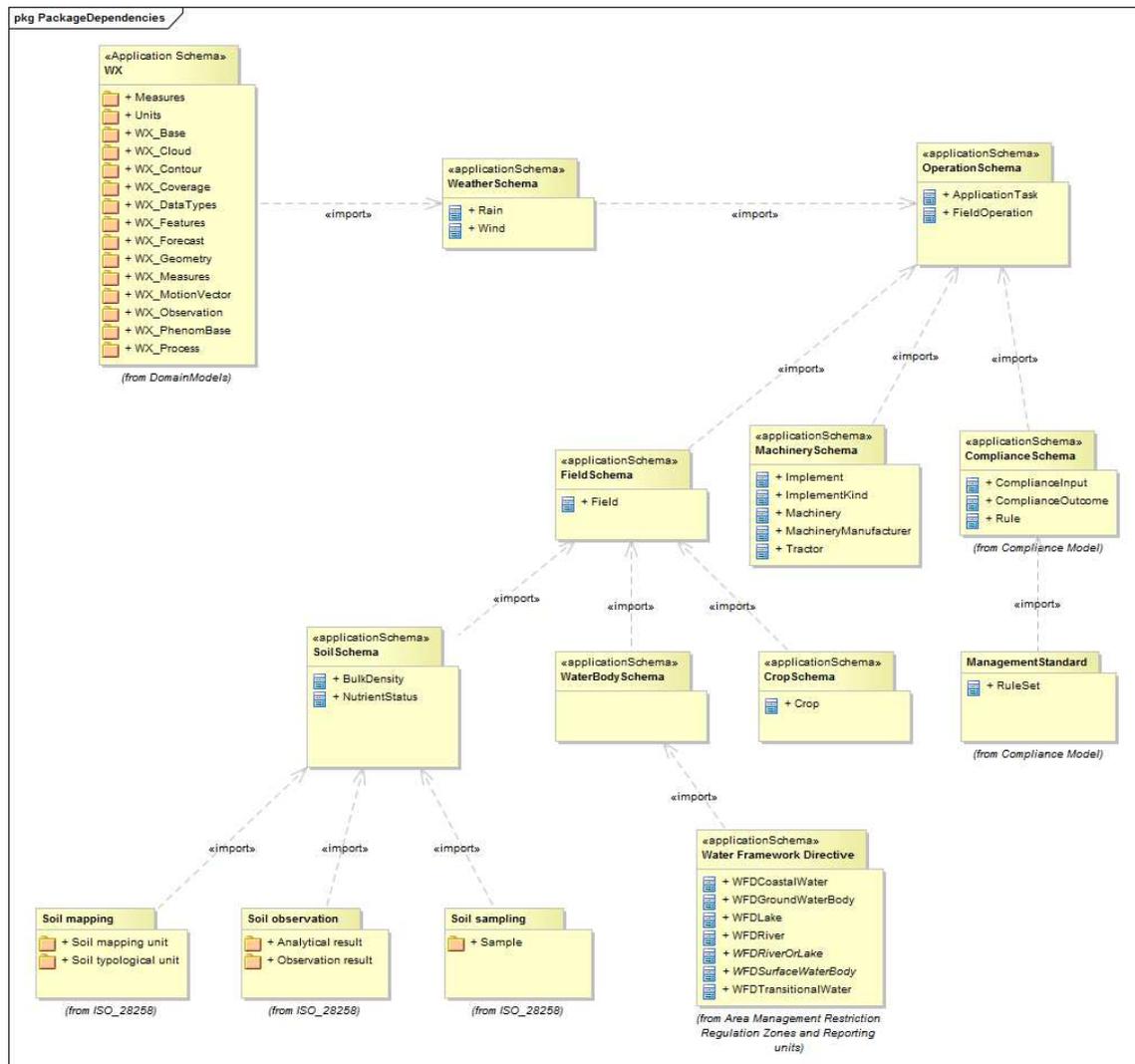


Figure 2: UML package diagram with imported packages from other SDI's

Some efforts of the INSPIRE directive already define various topics, which have overlapping elements which could be shared in a core theme (Tóth et al., 2012). In INSPIRE Annex III an application schema 'Water Framework Directive' (WFD) exists, which models different types of water bodies with the GML FeatureType GroundWaterBody. The WFD is linked to the payments for farmers from the Common Agricultural Policy and therefore relevant for nearly all European farmers. An agricultural application schema 'Compliance' could import and reuse relevant elements from the INSPIRE WFD schema. The range of possibilities for optimizing the applications can be enlarged with the implementation of further service nodes, available

C0107

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Sustainable Agriculture through ICT innovation

as SDI components. Their seamless interaction is possible due to common communication protocols and machine-readable and -interpretable geodata. Interesting additional standards and features are offered with the spatial rule interchange format (GeoRIF), sensor web enablement (SWE) and web processing services (WPS). Potential use cases might be the development and integration of standardized documentation technologies on the farm machinery, as well as the implementation of legal limits for nutrients (Nash et al., 2011) or field observations by sensors (Polojärvi et al., 2012). Additionally, processes for the analysis of complex data might be implemented more easily. ISO, OGC and the domain of geoinformatics already offer powerful tools for the definition and handling of spatial data. Precision agriculture can benefit from an implementation of these standards.

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C0107

J. Wiebenson, M. Jackenkroll. "Evaluation and Modelling of a Standard Based Spatial Data Infrastructure for Precision Farming". EFITA-WCCA-CIGR Conference "Sustainable Agriculture through ICT Innovation", Torino, Italy, 24-27 June 2013.