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Development of a Spatial Data Infrastructure for Precision Agriculture Applications

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Abbreviations and acronyms

AI artificial intelligence

CSW Catalog Service for the Web

DSS decision support system

FaaS Function-as-a-Service

FMIS farm management information system

FTP file transfer protocol

GIS geographic information system

GML Geography Markup Language

GNSS global navigation satellite system

GPS global positioning system

IoT Internet of Things

ISO International Organization of Standardization

IT information technology

OGC Open Geospatial Consortium Inc.

PA precision agriculture

PF precision farming

SDI Spatial Data Infrastructure

SOA service oriented architecture

SOS Sensor Observation Service

SWE Sensor Web Enablement

UAV unmanned aerial vehicle

XMPP Extensible Messaging and Presence Protocol

W3C World Wide Web Consortium

WCS Web Coverage Service

WFS Web Feature Service

WMS Web Map Service

WPS Web Processing Service

Summary

Precision agriculture (PA) is the technical answer to tackling heterogeneous conditions in a field. It works through site specific operations on a small scale and is driven by data. The objective is an optimized agricultural field application that is adaptable to local needs. The needs differ within a task by spatial conditions. A field, as a homogenous-planted unit, exceeds by its size the scale units of different landscape ecological properties, like soil type, slope, moisture content, solar radiation etc. Various PA-sensors sample data of the heterogeneous conditions in a field. PA-software and Farm Management Information Systems (FMIS) transfer the data into status information or application instructions, which are optimized for the local conditions.

The starting point of the research was the determination that the process of PA was only being used in individual environments without exchange between different users and to other domains. Data have been sampled regarding specific operations, but the model of PA suffers from these closed data streams and software products. Initial sensors, data processing and controlled implementations were constructed and sold as monolithic application. An exchange of hard- or software as well as of data was not planned. The design was focused on functionality in a fixed surrounding and conceived as being a unit. This has been identified as a disadvantage for ongoing developments and the creation of added value. Influences from the outside that may be innovative or even inspired cannot be considered. To make this possible, the underlying infrastructure must be flexible and optimized for the exchange of data.

This thesis explores the necessary data handling, in terms of integrating knowledge of other domains with a focus on the geo-spatial data processing. As PA is largely dependent on geographical data, this work develops spatial data infrastructure (SDI) components and is based on the methods and tools of geo-informatics. An SDI provides concepts for the organization of geospatial components. It consists of spatial- and metadata in geospatial workflows. The SDI in the center of these workflows is implemented by technologies, policies, arrangements, and interfaces to make the data accessible for various users. Data exchange is the major aim of the concept. As previously stated, data exchange is necessary for PA operations, and it can benefit from defined components of an SDI. Furthermore, PA-processes gain access to interchange with other domains. The import of additional, external data is a benefit. Simultaneously, an export interface for agricultural data offers new possibilities. Coordinated communication ensures understanding for each participant. From the technological point of view, standardized interfaces are best practice.

This work demonstrates the benefit of a standardized data exchange for PA, by using the standards of the Open Geospatial Consortium (OGC). The OGC develops and publishes a wide range of relevant standards, which are widely adopted in geospatially enabled software. They are practically proven in other domains and were implemented

partially in FMIS in the recent years. Depending on their focus, they could support software solutions by incorporating additional information for humans or machines into additional logics and algorithms. This work demonstrates the benefits of standardized data exchange for PA, especially by the standards of the OGC.

The process of research follows five objectives: (i) to increase the usability of PA-tools in order to open the technology for a wider group of users, (ii) to include external data and services seamlessly through standardized interfaces to PA-applications, (iii) to support exchange with other domains concerning data and technology, (iv) to create a modern PA-software architecture, which allows new players and known brands to support processes in PA and to develop new business segments, (v) to use IT-technologies as a driver for agriculture and to contribute to the digitalization of agriculture.

For this thesis, an optimized data handling, following the concept of an SDI, was analyzed concerning the transferability to PA and the initiated benefits from five publications or submitted manuscripts. Each single scientific work analyzed another field of PA processes. Through the research, a server environment, that followed the principles of an SDI with the interfaces of the OGC, was created.

In the first research paper, the concept of an SDI was carved out. The standards of the OGC were identified as appropriate for the needs of PA.

An implementation followed in the second paper. The OGC Web Mapping Services (WMS) and Web Feature Services (WFS) were integrated into agricultural operations and used to support a task controller in PA. A variable rate herbicide application has thus been enriched with external services for the driver and automatic decision making. The use of standardized services creates an especially high flexibility and makes the import from external sources possible with a minimum of coordination. The use of external sources could support the efficiency of working processes as well as helping with transparence. Economic and ecological benefits in the presented case were targeted by taking ground water zones into account as additional information.

PA was pushed forward by the development of technologies. Besides satellite navigation and increased calculation power, improvements in sensors stimulated the market of PA solutions. Unmanned Aerial Vehicles (UAV) especially gained an increasing meaning. The OGC offers comprehensive tools, listed under the OGC Sensor Web Enablement (SWE), for sensors and sensor networks. In the third paper, these were used for the real-time implementation of a UAV-field scan, combined with measurements from machine-mounted and local sensors, using a shared sensor data infrastructure. The infrastructure covers the control of the sensor systems, the access to their data, the data-transmission and standardized storage to improve the handling of sensor data during PA applications.

While OGC WMS and OGC WFS are standards for additional information in a working process, and the standards of the OGC SWE are developed for sensor networks, the OGC Web Processing Service (WPS) is an OGC-standard to implement geodata processing algorithms as services. This implementation of external logic was demonstrated in the fourth paper. Software developers are able to use this standard to focus on their strength and complex processing, which could be imported from specialists like scientists or consultants. The division of work is supported by technologies, which allow import from languages the domain-experts are used to, as in the presented example the statistical computing language R for scientists. Flexible FMIS, ready to work with the WPS, have an increasing range of functions. By adding highly specialized and only temporarily used functions from cloud services, the functional scope of an FMIS fits to the users' needs over the course of a year. In addition, the calculation-power can be adapted exactly to

the requirements.
The normed and standardized access of an SDI offers a low barrier for programmers. Standardization is a prime mover of the Internet of Things. Through the increase in accessibility, a combination with infrastructures of other domains is possible. As an instance, the fifth article of this thesis demonstrates this with a linkage to traffic information. In a conceptual analysis, technologies in hard- and software were used for a further benefit: positioning tools, network access and a standardized data management allowed the exchange of information with traffic information systems. By forwarding the position of agricultural machines entering or crossing public roads, an alert-system might reduce the risk of accidents between the machine and classical road users.
An SDI-concept in the backend of the PA data-environment enables a data- and service-ecosystem, which creates additional options and benefits for the PA-task. Moreover, while closed data streams can be used only for specific, individual needs, a clearly defined and standardized infrastructure expands options for the use of spatial data both from the machine's sensors and/or combined with them. External parties, like consultancies or the public sector, will also be enabled to cooperate digitally. Loss of data from broken information chains will be avoided. The agricultural value chain, as well as single field operations, will be supported. The farmer and society will profit from increasing the potential of PA.

Zusammenfassung

„Precision agriculture“ (PA) ist die technische Antwort, um heterogenen Bedingungen in einem Feld zu begegnen. Es arbeitet mit teilflächenspezifischen Handlungen kleinräumig und ist durch Daten angetrieben. Das Ziel ist die optimierte landwirtschaftliche Feldanwendung, welche an die lokalen Gegebenheiten angepasst wird. Die Bedürfnisse unterscheiden sich innerhalb einer Anwendung in den räumlichen Bedingungen. Ein Feld, als gleichmäßig bepflanzte Einheit, überschreitet in seiner Größe die räumlichen Einheiten verschiedener landschaftsökologischer Größen, wie den Bodentyp, die Hangneigung, den Feuchtigkeitsgehalt, die Sonneneinstrahlung etc. Unterschiedliche Sensoren sammeln Daten zu den heterogenen Bedingungen im Feld. PA-Software und „farm management information systems“ (FMIS) überführen die Daten in Statusinformationen oder Bearbeitungsanweisungen, die für die Bedingungen am Ort optimiert sind.
Ausgangspunkt dieser Dissertation war die Feststellung, dass der Prozess innerhalb von PA sich nur in einer individuellen Umgebung abspielte, ohne dass es einen Austausch zwischen verschiedenen Nutzern oder anderen Domänen gab. Daten wurden gezielt für Anwendungen gesammelt, aber das Modell von PA leidet unter diesen geschlossenen Datenströmen und Softwareprodukten. Ursprünglich wurden Sensoren, die Datenverarbeitung und die Steuerung von Anbaugeräten konstruiert und als monolithische Anwendung verkauft. Ein Austausch von Hard- und Software war ebenso nicht vorgesehen wie der von Daten. Das Design war auf Funktionen in einer festen Umgebung ausgerichtet und als eine Einheit konzipiert. Dieses zeigte sich als Nachteil für weitere Entwicklungen und bei der Erzeugung von Mehrwerten. Äußere innovative oder inspirierende Einflüsse können nicht berücksichtigt werden. Um dieses zu ermöglichen muss die darunterliegende Infrastruktur flexibel und auf einen Austausch von Daten optimiert sein.
Diese Dissertation erkundet die notwendige Datenverarbeitung im Sinne der Integration von Wissen aus anderen Bereichen mit dem Fokus auf der Verarbeitung von Geodaten. Da PA sehr abhängig von geographischen Daten ist, werden in dieser Arbeit die Bausteine einer Geodateninfrastruktur (GDI) entwickelt, die auf den Methoden und Werkzeugen der Geoinformatik beruhen. Eine GDI stellt Konzepte zur Organisation räumlicher Komponenten. Sie besteht aus Geodaten und Metadaten in raumbezogenen Arbeitsprozessen. Die GDI, als Zentrum dieser Arbeitsprozesse, wird mit Technologien, Richtlinien, Regelungen sowie Schnittstellen, die den Zugriff durch unterschiedliche Nutzer ermöglichen, umgesetzt. Datenaustausch ist das Hauptziel des Konzeptes. Wie bereits erwähnt, ist der Datenaustausch wichtig für PA-Tätigkeiten und er kann von den definierten Komponenten einer GDI profitieren. Ferner bereichert der Austausch mit anderen Gebieten die PA-Prozesse. Der Import zusätzlicher Daten ist daher ein Gewinn. Gleichzeitig bietet eine Export-Schnittstelle für landwirtschaftliche Daten neue Möglichkeiten. Koordinierte Kommunikation sichert das Verständnis für jeden Teilnehmer. Aus technischer Sicht sind standardisierte Schnittstellen die beste Lösung.

Diese Arbeit zeigt den Gewinn durch einen standardisierten Datenaustausch für PA, indem die Standards des „Open Geospatial Consortium“ (OGC) genutzt wurden. Der OGC entwickelt und publiziert eine Vielzahl von relevanten Standards, die eine große Reichweite in Geo-Software haben. Sie haben sich in der Praxis anderer Bereiche bewährt und wurden in den letzten Jahren teilweise in FMIS eingesetzt. Abhängig von ihrer Ausrichtung könnten sie Softwarelösungen unterstützen, indem sie zusätzliche Informationen für Menschen oder Maschinen in zusätzlicher Logik oder Algorithmen integrieren. Diese Arbeit zeigt die Vorzüge eines standardisierten Datenaustauschs für PA, insbesondere durch die Standards des OGC.

Die Ziele der Forschung waren: (i) die Nutzbarkeit von PA-Werkzeugen zu erhöhen und damit die Technologie einer breiteren Gruppe von Anwendern verfügbar zu machen, (ii) externe Daten und Dienste ohne Unterbrechung sowie über standardisierte Schnittstellen für PA-Anwendungen einzubeziehen, (iii) den Austausch mit anderen Bereichen im Bezug auf Daten und Technologien zu unterstützen, (iv) eine moderne PA-Softwarearchitektur zu erschaffen, die es neuen Teilnehmern und bekannten Marken ermöglicht, Prozesse in PA zu unterstützen und neue Geschäftsfelder zu entwickeln, (v) IT-Technologien als Antrieb für die Landwirtschaft zu nutzen und einen Beitrag zur Digitalisierung der Landwirtschaft zu leisten.

Für diese Dissertation wurde eine optimierte Datenverarbeitung, die dem Konzept einer GDI entspricht, im Bezug auf die Übertragbarkeit nach PA und die Vorteile aus fünf Publikationen oder eingereichten Manuskripten analysiert. Jede einzelne wissenschaftliche Arbeit untersucht ein anderes Feld von PA-Prozessen. Durch die Untersuchung wurde eine Serverumgebung aufgebaut, die den Prinzipien einer GDI mit den Schnittstellen einer OGC folgt.

Im ersten wissenschaftlichen Artikel wurde das Konzept einer GDI herausgearbeitet. Die Standards des OGC wurden für den Bedarf von PA benannt.

Eine Implementierung folgte in der zweiten Veröffentlichung. Der OGC Web Mapping Service und Web Feature Service (WFS) wurde in landwirtschaftliche Operationen integriert und verwendet, um eine Aufgabensteuerung für PA zu unterstützen. Eine Ausbringung variabler Raten beim Herbizideinsatz wurde so mit externen Diensten für den Fahrer und die automatische Entscheidungsfindung angereichert. Die Nutzung standardisierter Dienste schafft eine besonders hohe Flexibilität und macht den Import von externen Quellen ohne wesentlichen Koordinationsaufwand möglich. Die Nutzung externer Quellen kann die Effizienz von Arbeitsprozessen unterstützen und erhöht die Transparenz. Wirtschaftliche und ökologische Vorteile wurden im dargestellten Fall durch die Ausrichtung auf die Beachtung von Grundwasserzonen als zusätzliche Informationen berücksichtigt.

PA wurde durch die Entwicklung von Technologien gefördert. Neben Satellitennavigation und gestiegener Rechenleistung, waren es Verbesserungen an Sensoren, die den Markt von PA-Lösungen bewegten. „Unmanned Aerial Vehicles“ (UAV) gewannen an zunehmender Bedeutung. Das OGC bietet umfassende Werkzeuge, aufgeführt unter dem OGC Sensor Web Enablement (SWE), für Sensoren und Sensor-Netzwerke. In der dritten Veröffentlichung wurden diese für eine Echtzeitimplementierung einer UAV-Feldaufnahme, kombiniert mit Messungen von an der Maschine montierten und lokalen Sensoren, unter Verwendung einer verteilten Sensor-Dateninfrastruktur, genutzt. Die Infrastruktur umfasst die Kontrolle von Sensorsystemen, den Zugriff auf deren Daten, die Datenübertragung und standardisierte Speicherung, um die Verarbeitung von Sensordaten während einer PA-Anwendung zu verbessern.

Während OGC WMS und OGC WFS Standards für zusätzliche Informationen im Arbeitsprozess sind, und die Standards des OGC SWE für Sensornetzwerke entwickelt sind, ist der OGC Web Processing Service (WPS) ein OGC-Standard um Algorithmen zur Geodatenverarbeitung als Dienst zu implementieren. Diese Umsetzung von externer Logik wurde in der vierten Veröffentlichung dargestellt. Softwareentwickler können die Standards nutzen und sich auf ihre Stärken konzentrieren, während komplizierte Berechnungen von Spezialisten, wie Wissenschaftlern oder Beratern importiert werden. Die Arbeitsteilung wird durch die Technologie unterstützt, die es erlaubt, Sprachen von Fachexperten zu importieren, so im dargestellten Beispiel die Statistiksprache R von Wissenschaftlern. Flexible FMIS, eingerichtet für die Arbeit mit dem WPS, haben einen wachsenden Umfang an Funktionen. Durch hinzugefügte, hoch spezialisierte und nur kurzzeitig verwendete Funktionen von Cloud-Diensten passt der Funktionsumfang eines FMIS zu den Bedürfnissen eines Anwenders über den Jahresverlauf. Zusätzlich kann die Rechenleistung genau an die Bedürfnisse angepasst werden.
Der normierte und standardisierte Zugriff auf eine GDI bietet kleine Hürden für Programmierer. Standardisierung ist eine der treibenden Kräfte des „Internet of Things“. Durch den Wachstum der Zugriffsmöglichkeiten ist eine Kombination mit den Infrastrukturen anderer Gebiete möglich. Beispielhaft zeigt der fünfte Artikel dieser Dissertation durch eine Verbindung zur Verkehrsinformation. In einer konzeptionellen Analyse wurden Hard- und Software für weitere Vorteile verwendet: Lokalisierung, Netzzugriff und ein standardisiertes Datenmanagement erlaubt den Austausch von Informationen mit Verkehrsinformationssystemen. Durch die Mitteilung der Position einer landwirtschaftlichen Maschine, die in eine Straße einfährt oder diese kreuzt, ein Warnmeldesystem könnte das Risiko eines Unfalls zwischen Maschine und typischen Straßennutzer verringern.
Ein GDI-Konzept im Hintergrund einer PA-Datenverwaltung ermöglicht ein Daten- und Service-Ökosystem, das weitere Möglichkeiten und Vorteile für PA-Aufgaben schafft. Darüber hinaus erweitert es, während geschlossene Datenströme nur unter bestimmten, individuellen Zwecken verwendet werden können, durch eine klar definierte und standardisierte Infrastruktur die Möglichkeiten, Geodaten von den Sensoren der Maschine und/oder kombiniert zu nutzen. Externe Gruppen, wie Beratungsunternehmen oder der öffentliche Sektor, werden zudem in die Lage versetzt, digital zu kooperieren. Der Verlust von Daten durch gestörte Informationsflüsse wird verhindert. Die landwirtschaftliche Wertekette würde, genauso wie einzelne Feldbearbeitungen, unterstützt. Der Landwirt und die Gesellschaft würde von den wachsenden Möglichkeiten in PA profitieren.

Chapter 1

Introduction

Agricultural field operations, such as weed applications or crop production processes, aim on field-wide highest results by lowest input and unintended side-effects. Methods and tools were improved concerning these from the Neolithic period onwards. New technologies always influenced the way of cultivation and operations. Mostly ideas were imported from other areas than agriculture. Latest improvements were sensors and algorithms of decision support, coupled with information systems. Sensors detect the situation on the field on various levels. These high-resolution measurements of a field, combined with quantitative knowledge in algorithms, have a great potential for the optimizing of on-field processes. Simultaneously the won data make a type of data handling necessary that supports the process to information and coordinated operation. Computer and electronics offer the potential to improve processes and increase the quality and quantity of data, with information and knowledge ending up in a better result in the fieldwork. This process is location specific, which means field-, plot- or even plant-wise. The integration of these is under steady development. There are challenges, which have to be solved. Extensive knowledge about processes and modes of action, legal restrictions, historic and closed developed software solutions are some of them. Modern, coordinated data processing is necessary. A holistic architecture of the data infrastructure can face challenges in these area.

1.1 Agriculture pushed by IT-technologies: Precision agriculture

Agriculture, as a central need for the human living and prosperity, is under continuous development. Usually technologies from foreign areas were the driver of further improvements in agriculture (Karpinski 2014). Motorization, chemical products, genetic engineering and automation brought ideas and a hope for a "better" agriculture. Promising opportunities are offered by information technologies (IT). Since the last quarter of the 20th century, IT are highly acclaimed for their input and profit to other domains. The, so called, information age is also a pacemaker for agriculture.
Small, powerful computers, connected by networks enable complex analysis and data exchange in between almost every point worldwide. Combined with localization by satellite technologies, the discipline of precision agriculture (PA) was developed. PA, also called precision farming (PF), works with spatial knowledge and site-specific accuracy in operations. Every action targets in dose and location the specific circumstances in a

sub-regional view.
Auernhammer (2001) describes four core functions of PA, which are the control of implements, the farm management by documentation, the guidance of vehicles and the fleet management. The possibilities offer numerous advantages concerning an environment-friendly and economic-effective agriculture (Stafford 2000).
The farmer's or farm manager's main interests are direct visible results. Costs by productions means or working hours have to be reduced, or the quality or quantity of products has to increase. Besides documentation obligation about processed operations result in additional burden and could be reduced through PA-equipment. Ecological benefits are a welcomed side-effect for farm management by PA (Balafoutis et al. 2017). These positive effects for the society, as well as the ones for the farmer, could be reached by legal provisions (Clapp and Ruder 2020) or a reduction of barriers of PA in their technology. As additional technologies are an investment which has to calculated and new methods need trainings, the most PA used in practice, is on large-scale farms in developed countries (Balafoutis et al. 2017). These large-sized farms could be characterized by a higher degree of mechanization and larger homogenously treated fields. The new IT-methods help to treat the size of a field as not homogenous but rather as several smaller fields with specific needs. Especially in North America, the agriculture structure fits, and this was the first major market (Balafoutis et al. 2017). Other markets, like Europe or Asia, developed more slowly in this "first wave" of PA. Aulbur et al. (2019) identifies a second wave by a next generation of the technologies. Again, the technical infrastructure is the driver for this process and unfolds its potential also on smaller farms (Finger et al. 2019). Simultaneously society and politics discover the benefits for societal interest like nature protection. Thereby the weighting of arguments on PA changes.
At the beginning, the acceptance of PA was lower than the benefits promised. Several barriers delayed the leverage. In general, it is said, that the infrastructure below the electronics and software has a high potential to overcome existing barriers. The barriers are known and analyzed on the following different levels and characteristics: Stafford (2000) listed three barriers. He identified a need for software environments for the data processing, further the development of methods for PA operations and supporting technologies for sensing and applying. He identified them as challenges, which would be solved by the end of 2010. Working in that days in which the problems have been thought to be solved, Nash et al. (2009) and Sørensen et al. (2010) still noticed problems with the data handling and the PA data infrastructure. The usability of the solutions is a showstopper, and the benefits of their use are even known to farmers (Aubert et al. 2012). Moreover, even actual publications (Nikander et al. 2019) identified weaknesses with a missing standardization, a lack of options for farmers' notes and difficult operator interfaces.
During this last 20 years of PA-evolution IT developed further. Upwards from the design of web-based and service oriented architecture (SOA) (Nash et al. 2009), which is meanwhile implemented in some solutions on the market of agricultural software, the idea of the Internet of Things (IoT) occurs (Kaloxylos et al. 2012). Manufacturers noticed the trend, developed appropriate products and promoted these by labels like "smart farming" or "agriculture 4.0". Tzounis et al. (2017) anticipated the step from PA to micro-PA by bringing the idea of IoT to the domain of agriculture. Clapp and Ruder (2020) describes the terms as a connection of farm equipment and software platforms, as well as the emphasis of the fourth industrial revolution by digitalization in agriculture. Nevertheless, an IoT-product is not by the connection to the internet open and accessible

for all interested parties. For security or individual reasons, they are, not uncommon, capsulated solutions. As agricultural solutions existed before the trend of IoT started, the products were complemented by additional functions and features. Moreover, a few got a complete re-design. Thereby the communication is usually not structured and has to be organized by an extra module of software in-between (called middleware).
Closely linked to IoT is the term of cloud computing, as IoT produces much data (Elijah et al. 2018). Therefore, a cloud infrastructure provides an almost unlimited data store and computing power. The market offers such solutions for agriculture. Farmers give their data to the manufacturer who might further offer additional services. Simultaneously the company has access to "big data"—another key word of nowadays—information management. The "big data" datasets are of interest for further developments to generate new products. However, they bring another barrier: The farm's data contain a lot of knowledge about the processes and characteristics of the field. The owners want to share them only with trusted parties. Clapp and Ruder (2020) warns concerning unsolved ownership relations.
IT is influencing agriculture more than every other trend (Maloku et al. 2020). Over time established (software-) solutions have to be redesigned. A rethinking takes place. The whole concept of farming software and data handling has to be and is being re-invented. New formats, the use of standards, service-oriented architecture, external data sources, sensor networks etc. are some of the ideas that were combined with the applications of agriculture.
In respect to these challenges, there were state- and organization-fundings to push the development of PA by working on this topic. Three of them, influencing the following work, are to be mentioned: The European GeoWebAgri I and II projects, dealt with the transfer of standards from spatial science to PA-machinery and to map PA-applications in data-schemas. Further, the Carl-Zeiss-foundation supports research on sensors and the data handling by setting up the competence center for sensor technologies and geographical information systems (SenGIS) to support their improvement and their integration into practical farm works.
After more than 30 years of PA the products on the market developed and integrated ideas from science concerning the benefit of information technologies. Nowadays agriculture software solutions partly work on services and integrate external data. There are some standardized interfaces in use. Further the idea of cloud-oriented working is getting more and more popular. Nevertheless PA might benefit from further, and more concrete, integration of the available concepts.

1.2 Spatial data as main information for precision agriculture processes

PA is based on the principle of location specific adjustments in the agricultural work. This can be done, because of a spatial knowledge. Spatial knowledge could be acquired by on-site sensing and needs real-time operations, which is attached to fast and simple data processing and field work. For more complex analysis or taking the past—or external, spatially changing—information into account, a geo-mapping is required. Here the location, represented by one (point) or more coordinates (line or polygon), is most relevant. Whatever kind of geographic information is used, the homogenous characteristic of a field is separated into location-related information. By definition, there is no required level of detail, as PA is used on most varied levels above field scale.

Mapping in PA is possible since a machine knows about its position. The decisive factor was the public access of satellite positioning systems, the so-called global navigation satellite system (GNSS). The United American global positioning system (GPS) first, followed by the Russian GLONASS, the European Galileo and the Chinese BeiDou make global positioning, besides regional Japanese and Indian solutions, possible. Since 1995, the GPS-signals offer a positioning of an accuracy of an upper tens of meters for civil uses. It was further improved to a precision of few meters. By additional correction methods (e.g. Real Time Kinematic) an accuracy of centimeters is possible nowadays. While the standard accuracy is under good conditions sufficient for simple PA operations, the correction allows plant specific work.

The development of sensors supplements the use of positioning systems in PA. The spatial, as well as all other, resolutions of field data increased. Data from manifold sensor-platforms were tested and improved. Research about the different agriculture application scenarios are published, e.g. Machleb et al. (2020), Zecha et al. (2018), Vázquez-Arellano et al. (2016).

Acknowledging the potential of spatial information, manufacturers designed their products. The number of GNSS-ready machines steady increases. Over 500.000 GNSS-devices were sold in agriculture in 2018. Tractor guidance is the major use, followed by automatic steering, variable rate technologies and asset management (GSA 2019). Its main distribution is in developed countries and on bigger farms (Finger et al. 2019). Besides the North American and European market, Asia is getting more and more important concerning the use of GNSS in agriculture (GSA 2019). The global market of PA is expected to grow. In 2017 it was estimated by USD 3.4 billion and prognosed to USD 5.5 billion in 2021 (Aulbur et al. 2019).

Aulbur et al. (2019) identified four technologies as essential for the development of PA and equates them with the future of farming. These are the fields of sensing, automation and digitalization, including the methodology of big data and biologicals. At least the three first mentioned are linked to IT.

Farmers and farm managers use software to manage and prepare their PA field operations. Such solutions are called farm management information system (FMIS), which bundle farm data and prepare them for further operations (Sørensen et al. 2010). During the last decade, the offered products changed from local software to web-based solutions. Another component in agriculture data treatment, partially included in FMIS-solutions, are decision support system (DSS). These support the decision-making about the if and how of an operation. The web as location of operation makes the FMIS, and DSS as well, more flexible. Different clients support a wider field of application.

Beside the user oriented view of agricultural data handling there is the close-to-machine data handling, realized with the machine data-bus. In general, this is done by the ISOBUS-standard. The ISOBUS-standard ISO11783 is common in modern machinery, in particular in PA use-cases. The AEF TC-GEO, as an extension of the ISOBUS standard, adds the possibility of im- and export in the ISO-XML-language, focusing on spatial information. ISO-XML is designed for a compact machine-to-machine-communication (Korduan 2005). It uses a standard of the World Wide Web Consortium: the Extensible Markup Language (XML). XML is a meta-language offering the framework for domain specific languages and is human- and machine-readable. Another realization in XML in the field of agriculture is agroXML. In contrast to ISO-XML the agroXML-language was developed to represent the production- and foodchain (Doluschitz et al. 2005). It is used for the exchange to office applications. Thereby the integration of multiple parties

is its strength. Both languages do not have the demands of PA-operations in focus. The work area of strategic and tactical planning, task management and field operation is not adequately included (Nørremark et al. 2013).
The spatial data handling in the software products for agriculture on the market takes place in more or less closed systems. Often data imports are only enabled to other known systems. Besides the mentioned XML-formats from agriculture for spatial data, the ESRI shape-file-format is still state of art in agriculture-software technologies. After over 20 years without further developments in this proprietary de-facto standard, it has limitations. Geoinformatics offer more appropriate formats to overcome these. Nevertheless, the question of data handling needs a holistic concept. According to that challenge, the geo data handling could be optimized to spatial processes. The methods are in use in the information systems and infrastructures of several other domains. The idea of an integration in PA is obvious. Standardized interfaces are available, which are flexible and offer further benefits. The solution approach for spatial data handling is called the Spatial Data Infrastructure (SDI). SDI's focus on complex digital environments, where all stakeholders can interact on the level of data exchange (Phillips et al. 1999). It is optimized for support planning and decision making on spatial information (Phillips et al. 1999) between multiple users. An SDI is defined as

> "a basis for spatial data discovery, evaluation, and application for users and providers within all levels of government, the commercial sector, the non-profit sector, academia and by citizens in general." (Nebert 2009).

It mainly consists of four components, which are the spatial data, on-building data services, describing metadata and the environment in which the exchange takes place. Williamson et al. (2003) adds, to the before mentioned data and access networks, the users and policies and standards, whereby these overlap with regards to the meaning of the previous.
As services are of a central meaning in this work, the common understanding of this term is important. Services are seen as web-accessible interfaces for access to one or more capabilities. Their possibilites for requests and underlying configuration is fixed (MacKenzie et al. 2006).
Per definition, a distinction can be made to terms like a geodatabase or a geographic information system (GIS). The database can be one element of an SDI, as it is the storage for data, but it does not cover their exchange, processing and description. A GIS is defined by its data, users, processes, software and hardware. From the users view, it focuses on a software dealing with spatial data. It is more concentrated and could be understood as a toolbox for spatial data. An SDI has a more general view and describes a comprehensive working environment for spatial data.
Interoperability as the central objective of an SDI is of a high importance in PA. It takes place between the different user-groups, which are farmers, farming machines, agricultural consultants, companies and manufacturers, public authorities and scientists. By the concept of a middleware, improving the communication between different levels of abstraction in the holistic data handling, an SDI is integrable into a domain. Accepted standards of a domain, like the ISO 11783 ("ISOBUS") for agricultural machines have to be included. The same is important for standards in domains of accompanying technologies. The standards of the World Wide Web Consortium (W3C) have to mention, similar to several, additional and overlapping standards of the (ISO). The ISO 19100-standards are based on the developments of the Open Geospatial Consortium Inc. (OGC), which published further descriptions that are relevant for SDIs in PA.

Including the developments from foreign fields has improved and will further improve processes in the domain of agriculture. Therefore, the methodology and knowledge of the domain of spatial information has a key role for PA.

Korduan and Nash (2005) presents a first draft for an SDI for precision farming, implementing external data by geo-data services. Steinberger et al. (2009) faces the same challenge and transferred it to an ISOBUS-standardized environment. He linked the ISOBUS to an FMIS by agroXML. Both added additional data to a user interface. Nørremark et al. (2013) did a further step, by opening the data flow in both directions, using standardized spatial services for field data. The ideas of Nash et al. (2009) go even further - he analyzed the toolbox of the domain of spatial data and presented, besides the general services for data integration, specialized standards for sensors and processing. According the needs of an SDI there are also options for metadata-descriptions. Korduan and Nash (2005) described the integration of the different standards. This clearly demonstrates how important metadata are for the usability of a data infrastructure.

The development in IT since the first studies in SDI's for PA is enormous. The power of processors increased, the accessibility of mobile internet expanded, and it is a matter of fact that everyone carries a smart telephone, which is a powerful, internet connected computer, around. Further on, the concepts of an SDI are in place. In the period of the origin of PA, all components worked separately. In-between the farm manager had to transfer the data from sampling to preparing and processing and analyzing to consulting and operating. Some of these steps are automated today. Nevertheless, the usability was always a lack of the used solutions and a slot for data carriers is still usual for the hardware. Moreover, individual improvements led to closed processes, as manufacturer mapped only their special business case. Thus, manifold autonomous PA solutions emerged. There were still barriers for the user in the interaction with further elements or partners in PA. Since manufacturers in agriculture work on the integration of their software into their product range, they professionalize them. Partly completed new developments are necessary. Customers benefit by improved processes and a higher usability.

We can work out four categories of PA infrastructure concerning the handling of spatial data, which might stand for four different levels of evaluation:

1. separated components; data treatment by active user; manual, file-based data transfer
2. components in capsulated environments for specific use cases; automated data processing; if necessary manual, file-based data transfer
3. components in the environment of brands or partners; automated data processing; selected interfaces to the outer world
4. components as services in a domain ecosystem; automated, but customizable, data processing; domain-unspecific, data-type specific interfaces

In practice, there might be slight variances from these categories, but in general, they represent the successive development and objective of the spatial data handling in PA. From step three onwards, the environment fit to the theory of an SDI, as data are getting dynamic in their environment.

Regarding the ambitions of reaching "agriculture 4.0", it is necessary to overcome the current limitations of spatial data handling to open the infrastructure and to involve a

wider circle of parties. A modern SDI is characterized by the features of a standardized data exchange with general accepted services to improve the sampling, exchange and processing of data.
Thereby the knowledge of geoinformatics become relevant for an improved data handling in PA.

1.3 Objectives

In this thesis an SDI is developed to improve the data handling in PA and PA itself. Therefore, the theory of an SDI from geoinformatics was applied in agriculture. The focus is on the use of a standardized data exchange, improving existing business processes and creating new options for further developments. Therefore, the integration of data into working processes, the flow of sensor scans and their processing is analyzed, as well as the exchange with infrastructures of other domains.
The objectives were:

- to increase the usability of PA-tools in order to open the technology for a wider group of users,
- to include external data and services seamlessly through standardized interfaces to PA-applications,
- to support exchange with other domains concerning data and technology,
- to create a modern PA-software architecture, which allows new players and known brands to support processes in PA and to develop new business segments,
- to use IT as a driver for agriculture and to contribute to the digitalization of agriculture.

1.4 Structure

Section 1 explains how information technologies drive PA and how it benefits from the input. It further points to existing barriers and explains why methods and tools might fill this gap. In addition to selected research in this field, it describes how products implemented ideas from geoinformatics. Through the idea of an SDI, it names a concept, which will be analyzed in more detail by the following sections by listed objectives and the described structure.
Section 2 gives an overview about the components of an SDI and relevant standards for spatial data. Through the example of an agriculture research center, their role in PA operations is analyzed. In particular, the meaning of sensors and the handling of their data is described. In case studies tools are connected to PA-operations.
Section 3 presents an application of two data standards, one for the mapping of raster- and one for vector-information, in a PA environment. The additional information imported by these are connected to a task controller, which represents the bridge to the ISOBUS-environment of a tractor. Firstly the standardized interfaces are used for additional information for the driver, and secondly for the import of public boarders of ground water and flood risk areas, to control via the ISOBUS a variable rate spraying case with regards to water safety.

Section 4 applied another spatial standard, focusing on the integration of sensors into an SDI. The field trial combined a sensors at an unmanned aerial vehicle (UAV), at a tractor and local sensors, delivering their data to a field computer. Therefore, a sensor integration layer, as an independent software unit, was developed, which forwards the data to a sensor web layer, integrating and storing all measured data. Section 5 provides a further element for an SDI for PA: the focus is on the processing of data. Therefore again, a standardized interface is used and applied in the calculation of a vegetation index. Simultaneously the concept of processing standards as Function-as-a-Service is analyzed. It provides a concept how SDI's could implemented into actual business processes in PA.

Section 6 illustrates the benefits of standardized interfaces by an example concerning the use of information from PA. Therefore, a use-case from traffic information visualize how such datasets could be mapped into a foreign domain. Advantages of the collaboration are reduced risks for accidents on roads, in which agricultural machines are involved.

Section 1 is a peer-reviewed book chapter, which has been published by the Czech Centre for Science and Society (České centrum pro vědu a společnost). Section 2–3 consists of articles that have been published and section 4–5 of articles that have been submitted to international, peer-reviewed scientific journals. In section 6, the results of the above sections are discussed. Therefore, it follows the objectives of section 1 and gives an outlook for further research and development.

Chapter 2

Competence centre SenGIS – exploring methods for georeferenced multi-sensor data acquisition, storage, handling and analysis

Keller, M., C. Zecha, M. Jackenkroll, M. Weis, J. Link-Dolezal, R. Gerhards and W. Claupein (2012). Competence centre SenGIS – exploring methods for georeferenced multi-sensor data acquisition, storage, handling and analysis. In T. Mildorf, K. Charvat (Eds.), ICT for agriculture, rural development and environment: Where we are? Where we will go? (pp. 218–229). Czech Centre for Science & Society, Prague, Czech Republic.

With the idea of PF a new era of agriculture began. Electronic developments like positioning systems, high-resolution sensors and small, powerful computing units enabled an optimization of field work. The University of Hohenheim identified two development areas: sensors and GIS. The "Competence Centre for Sensors and Geoinformation Systems" (SenGIS) focused the research on these topics. A mobile, ground research platform "Sensicle" combined with an UAV allowed the testing of manifold sensors and the combination of their measurements. A further element was the data storage and management. Therefore, a spatial data infrastructure was developed, dealing with the topic of seamless data management and the integration of data sources into FMIS.
This publication gives an overview about the facilities of the competence center. Simultaneously, it outlines potential improvements of PF. Concerning the present work these improvements are the components for a professional spatial data handling. Besides the GIS-component as the central element of software, the data-exchange has an important role in an improved data handling in agriculture. Therefore, an SDI benefits from a SOA and standardized interfaces. With their spatial background, the standards of the OGC fit best to the demands of PF. The listed standards show the range of data they could deal with. Metadata are another element for a user friendly SDI, as the exchange of data is only reasonable by understanding their content.

In three case-studies the practical potential of the developed solutions is analyzed. Regarding the management for scientific data, it presents the opportunities, which are created by standardized interfaces for further use.
In conclusion, the paper gives an overview of the possibilities and development potential of PF. Therefore, an integrated approach has been chosen. The developments include all parts of PF and present in detail the SDI as a central element for improved data handing.

Abstract

PA benefits by the combination of measurements from manifold sensors. While single-sensor solutions are offered on the market of agricultural machinery the comprehensive infrastructure is a lack in agricultural data handling. The competence centre SenGIS at University of Hohenheim (Stuttgart, Germany) addresses this, by doing research on methods of data acquisition, storage, handling and analysis in site-specific productions and the practices of management. Identifying the complexity of data handling and preparation for application as a main reason for the acceptance of sensor technologies in agriculture, SenGIS studied different sensors on ground- and air-based platforms under field conditions as well, as the onward data processing in a spatial data infrastructure. The described spatial data management is build up on a geodatabase and standardized interfaces for the exchange of data. Illustrated by three case studies the interdisciplinary work of SenGIS is presented.

The publication is available at: https://otik.uk.zcu.cz/bitstream/11025/982/1/ictbook-120613124719-phpapp02.pdf

Chapter 3

Automatic control of farming operations based on spatial web services

Kaivosoja, J., Jackenkroll, M., Linkolehto, R., Weis, M., and Gerhards, R. (2014). Automatic control of farming operations based on spatial web services. Computers and Electronics in Agriculture, 100, 110-115.

Section 1 presented the theoretical framework of a PF infrastructure, working on services and standards. In this research, the framework is transferred to a field operation.
Sørensen et al. 2010 notes that the integration of additional information and, therefore, user friendly technologies are elementary for farm managers. The technological approach uses services from the OGC. They are standardized and developed for a spatial use. This is an optimal characteristic for PF-tasks. Machines are the central tool for field operations. Nowadays information technologies support the driver. Furthermore, the driver is able to more or less control every object of a modern tractor and device. The flow of information between the machinery and the driver passes by the task controller as a central electronic unit, which is in charge of the operations. As all modern devices in agriculture use the ISOBUS standard for internal and external communication, the key development in this research is a task controller in an ISOBUS environment that integrates external data. The task controller imports data from a File Transfer Protocol (FTP)-server and different services, standardized to the OGC, as an additional feature. This infrastructure is used for a precision spraying task in which the OGC WMS and WFS offer additional information to driver and machine. While the WMS supports the human with further information through images behind the application map, the WFS offers spatial information for computing in the task controller. The integration of an external service to the machine is of special interest, as it represents information from the state sector (in this case, areas of a specific protection). Also other sources could be integrated into a PF process by the designed infrastructure. The standardized interfaces allow an increase of the usability for complex PF-tasks.

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Automatic control of farming operations based on spatial web services

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ABSTRACT

Field operations relating to arable farming are often very data intensive tasks. An increasing number of regulations have been set to ensure food safety and environmental aspects. Also, the number of tools for the best practice management applied in precision agriculture is growing. However, there are yet no standardized, automated methods for a compliance management used in situations where circumstances change and are dependent on the specific location. Therefore compliance checks during the work progress online or on demand are difficult to achieve and the temporal accuracy can be very poor. In this work, we have developed a task controller (TC) prototype with an ISOBUS-compatible process data messages to be able to utilize multiple external services such as WFS (Web Feature Service) during a spraying operation. The WFS was set up in Germany to provide geodata while the actual task execution was performed in Finland. We developed a possibility to use and integrate external data from different sources in the TC on the tractor. Methods presented in this article serve as the basis for the development of multiple tools that can be used for improving farming system development, the environmental risk reduction of agricultural production and compliance checks. Existing information sources such as on board sensors, weather and forecast information, disease pressure, spatial environmental risks and real time remote sensing can be combined for new solutions of this kind. The development of technical standards for the seamless data exchange in the agricultural domain is therefore crucial. In this work, we are focussing on spatial data exchange between heterogeneous IT systems as a component of on-field machinery used in precision management.

1. Introduction

Field operations on arable farming often require very data intensive and thorough planning. Changing conditions may cause various difficulties even when the operational plan is made with proper preparations. One of the key concerns of the farm managers as summarized by Sørensen et al. (2010) is that monitoring of field operations is time consuming and that there is a need for additional information and advanced technologies to manage monitoring and data acquisition online in the field.

In the last two decades there has been an increase in the number of legal regulations to confirm. Guidelines concerning food safety and environmental acts like fertilization of nutrients, the use of pesticides and seed types affect all farmers. There are also voluntary standards to show compliance to stricter requirements for products (Jahn et al., 2005; Fulponi, 2006) such as the EU Organic standard (EU Regulation 834/2007) or privately-run industry standards e.g. GlobalGAP (2007). A higher price level for specialized production and better food quality can be a driving factor for compliance to stricter standards. According to Nash et al. (2011), these agricultural standards are composed of a set of rules including metadata describing the publisher, the intention of the publisher, the spatiotemporal validity, the target audience, procedures in the event of non-compliance, a definition of terms used and how compliance to the rule is to be assessed. Integration of these rules into an automated management procedure is required to provide a better spatial and temporal response.

FMIS (Farm Management Information Systems) are developed to support management decision making and compliance to management standards by means of storing and processing of strategic,

Abbreviations: CAN, controller area network; FMIS, Farm Management Information System; FTP, File Transfer Protocol; GDB, geodatabase; GeoRIF, Geographic Rule Interchange Format; GML, Geography Markup Language; HTTPS, Hypertext Transfer Protocol Secure; I-ECU, Electronic Control Unit of the Implement; LBS, location based service; MBR, Minimum Bounding Rectangle; MICS, mobile implement control system; NDVI, Normalized Difference Vegetation Index; OGC, Open Geospatial Consortium, Inc.; PDM, process data message; R-TC, prototype research task controller; SDI, Spatial Data Infrastructure; SOA, Service-Oriented Architecture; SSL, Secure Sockets Layer; TC, task controller; WFS, Web Feature Service; WFS-T, Transactional Web Feature Service; WMS, Web Map Service; WPS, Web Processing Service.

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tactical, operational and evaluation data. Typically many of the agricultural production standards are already hard-coded in the FMIS instead of obtaining that data from external sources. However, this approach is unsuitable in the long term due to the dynamic nature of agricultural production standards which are replaced and revised in irregular intervals (Nikkilä et al., 2012). They may only be valid for a limited group of farmers (e.g. country-wise, crop-wise). Therefore, more effort is needed for transferring regulations between IT systems and to provide means for an integration and interpretation of such rules in decision- and management support tools. A conceptual model of a modern FMIS suitable for automated compliance control is given by Sørensen et al. (2010).

Nikkilä et al. (2012) presented an evaluation web-service exploiting a spatial GeoRIF (Geographic Rule Interchange Format) interpreter for the automated compliance control. The application task was exposed to the automated compliance control before the field operation. After the field operation, the constructed operational document was checked again. Their work was further developed to present a design for spatial inference using an interchangeable rule format (Nikkilä et al., 2013). However, there are neither standardized methods nor technical implementations for managing compliance to standards, regulations or best practices during the work progress online or on demand. The lack of these methods leads inaccurate, inefficient and generalized decisions during the farming operation. Changing conditions like current rain and wind, pesticide alarms, weather forecasts, applicable matter content changes, working schedules, work applied by other working units, different risk analysis, information from aerial systems or advisory recommendations require a rapid update for the optimization of the operational plan and the adaption of the task in the field. When such changes occur, it would be profitable to be able to check and update automatically whether and how the relevant rules, regulations and best practices are still fulfilled. IT systems are the key component for such automated procedures, including, but not limited to FMIS.

Especially tasks in precision farming field operations can be quite complex. Rather than constructing and evaluating a single complete task, it would be better to evaluate all the individual, separate spatial decisions which form the task in hand. These decisions can be made based on available spatial and rule-based data sets. Those data sets incorporate the actual, local situation of the farm and down to the scale of variations within each field. In this context, the web service standards for geospatial data exchange are important. They apply Service-Oriented Architecture (SOA) as a software architecture design.

1.1. Suitable spatial web services

SOA allows information exchange on-demand between distributed systems. Often only particular data values or information related to a particular object or spatial extent is required. This has also been one of the focuses of standardization based the work of the ISO/TC211 Geographic Information/Geomatics and the Open Geospatial Consortium, Inc. (OGC).

As a result of the INSPIRE directive 2007/2/EC, many of the spatial data sources have gained public availability often by providing a Web Map Service (WMS) or a Web Feature Service (WFS) e.g. German GDI-DE (IMAGI, 2009) and Finnish Paikkatietoikkuna (NLS, 2010). Including these services into the farming operation would make it possible to have beneficial up-to-date sources of data, which would also be following common standards. One example of this is the development of making customized agricultural services, such as local disease status as a WMS (Ronkainen et al., 2012).

The output of a WMS is mainly used for the presentation of geodata for a human user by mapping background imagery together with additional layers of information or to summarise data (Nash et al., 2009a). For a machine interpretation of a single object's information, more suitable output becomes from a feature-oriented WFS. The development of WFS made progress in the ISO 19142. WFS is a data query mechanism to access and retrieve data in real time over the web. The potential scopes of application in the agriculture domain are processes of reading free scalable vector data, documentation and controlling. In general a request to the WFS is answered in the Geography Markup Language (GML). GML is also a standard developed by the OGC and transferred to ISO 19136. It is a markup language developed to describe geographic objects. Korduan and Nash (2005) identified it as a suitable format for geographic data on precision agriculture. Based on a study of Nørremark and Sørensen (2012), there is an ongoing research on adapting transactional WFS (WFS-T) capabilities to a task controller in Denmark.

1.2. ISOBUS environment

To adapt possible changes caused by some external data in farming operation, it is necessary to be able to deliver a proper message to the Electronic Control Unit of the Implement (I-ECU). To control the implement in a standardized way, the idea of ISOBUS Task Controller (TC) has been introduced. ISOBUS has already gained a relatively large market share over the last decade and is implemented by many manufacturers. ISO/FDIS 11783-10 (ISO, 2007) is a standardized interface relating to communication at the software level between FMIS and mobile implement control system (MICS) using board computers (ISOBUS-TC). TC uses XML-based formats for communication with FMIS, and Process Data Messages (PDM) via controller area network (CAN) bus to communicate with the I-ECU. TC handles data setup and machine configurations and also takes care of the documentation of the work executed by the mobile system. For the spatial working rate changes of the implement, TC uses an ISOBUS task map. So far the ISOBUS task has been considered to be structured as one task per one work. In practice, a planned task is selected from a drop list at the beginning of the work. Then the entire work is done according to it.

Commercial systems that exploit external sensor information like special on-board cameras still have their own controllers when operating with ISOBUS-machinery. Earlier research related to ISOBUS-TC and data transfer has had its focus on an XML-based transfer of data from the FMIS to onboard devices and in a data dictionary of identifiers for process data variables and data elements (Nash et al., 2009b). Peets et al. (2012) studied collection and management of data acquired from ISO 11783 compliant and non-compliant on-the-go sensors, but their focus was also on data collection, not exploiting it during the work. The work by Iftikhar and Pedersen (2011) focused on the exchange of data between the farming devices also including climate control and production monitoring equipment, temperature monitoring sensor and the farming systems featuring agricultural advisory service, supplier, contractor and manufacturers. The solution focused on ISOBUS-available functions. However, there has not been research on exploiting multiple spatial web services during farming operation or implementing them into an ISOBUS environment.

1.3. Research focus

In this study, the focus is in the following scenario: a farmer wants to operate according to the new environmental rules which also contain spatial restrictions and are provided by different authors. The application task for precision spraying has been planned according to these rules, but in order for this plan to succeed, the weather needs to be suitable. There is also an accurate spatial disease status for **Drechslera teres** available on the web. The actual spatiotemporal application rate is determined by smartly combining those different sources together with weather information. Even when acting with rather static rules, the application task can be dynamically changed according to the current conditions. With current methods, the spatial accuracy of the work can be relatively high while instead the temporal accuracy is low when non up-to-date information is used for an optimisation or compliance checks.

This research has three objectives: integrate multiple external spatial data sources into the task execution process, outline a dynamic application task for precision farming and to discuss possibilities that this kind of data integration could provide. The rest of this paper is structured as follows. Section 2 introduces the applied material and methods introducing the implementations of web service and task controller. In the third section, we present the implementation results by using a precision spraying case study. We discuss the results and their practicality in the fourth section. Section 5 concludes the paper.

2. Materials and methods

We constructed a pesticide spraying case study to outline the requirements of a system that could perform operations such as the presented scenario. We included services capable of providing WFS and WMS data according to OGC standards and a task controller capable of exploiting them. We also used an FTP server to provide weather information.

As a background for our TC work are the prototypes of ISOBUS compatible TCs (Miettinen et al., 2006; Ojanne et al., 2009) that have been developed for research purposes. Based on the gained knowledge of those implementations, we constructed a Research Task Controller (R-TC) operating in a LabVIEW-environment. The constructed R-TC is equipped with ISOBUS compatible process data message capabilities.

We developed a variable rate application (VRA) task as a basis for the spraying case. The task was located on a research field in Finland. To demonstrate the independence of the location of SDI components, we used one external WMS source and a geodata server at University of Hohenheim providing data such as the VRA task, field boundaries, groundwater and classified flood risk data.

Due to winter weather conditions, the tests were carried out as simulations. We fed realistic tractor data to the CAN-bus and read it with our R-TC. Previously logged GPS information was read from a file by the R-TC. The R-TC read new GPS-coordinates with 5 Hz frequency.

2.1. Web service implementation

Following the principles presented by Williamson et al. (2003), a flexible SDI (Spatial Data Infrastructure) was built up. The central elements were geodata stores. Storage took place in a geodatabase (GDB). A PostgreSQL[1] database with a PostGIS[2] extension formed the high performance data storage for multidimensional data. The publication and output of data were realized via a webserver based on Apache2[3] and Tomcat 6[4] as application frameworks. Applications, which were installed and configured in these frameworks, were GeoServer,[5] GeoNetwork Opensource[6] and Mapbender.[7] We used these applications to publish and view data (and metadata) according to ISO- and OGC-standards.

We published a map for the R-TC by applying the GeoServer's WFS. The access authority of the GeoServer software was configured to protect the service against unwanted sharing of data to third parties. To protect the information exchange over the web, all communication with the server took place via secured http (HTTPS, Hypertext Transfer Protocol Secure) transferring information encrypted over a Secure Sockets Layer (SSL).

While the WMS offers a human-readable cartographic image for the assisting information, the TC itself needs machine-readable and -interpretable information to support the precision spraying task in the action. In our case study, we used areas of ground water (SYKE, 2012), flood risk and field boundaries as an input data. The GeoServer application published them via WFS for the TC's user interface as vector oriented GML-files. Data originated from the same data set as presented by WMS. The theory behind, as well as the main differences between WMS, WFS and GML, are described by the official webpage of the OGC.[8]

2.2. Task controller implementation

First, we enabled GML-files to serve as the data format for the application task. For the background image, we applied a customized coordinate transformation to the WGS 84 coordinates from the metric coordinate system where the image was referenced. We used Minimum Bounding Rectangle (MBR) calculation for the field boundaries to determine the minimum required extent of the image.

We brought the weather and forecast information to the R-TC by using methods developed in MTT's ongoing project Envisense (Thessler et al., 2011; Huitu et al., 2012). The weather and forecast information were located in an FTP (File Transfer Protocol) server as an XML file. It included information about time, air temperature, air humidity, rainfall, rain probability, wind direction, wind speed, air pressure, soil temperature and soil humidity. Information was gathered from four different weather stations. For this research, we used values determined by a single, nearby weather station and rain forecast externally calculated to that weather station.

The constructed system used inputs from five data sources (Fig. 1). The VRA task and ground water data were transferred from WFS. The flood risk and background maps were taken from the WMS and weather and forecast information were received from the FTP server. For the point-in-polygon determination with each data originating from the WFS, we used a traditional ray casting algorithm (Sutherland et al., 1974).

3. Implementation results

The result of this work is the working principle of the developed R-TC capable of command ISOBUS-compatible sprayer equipment together with the developed spatial data services. The developed R-TC utilises data from WFS, WMS and FTP-server and combines them into a variable rate amount decision in real time. The simple equation for the spraying amount is:

$$\text{Amount} = \frac{\text{AR} * \text{VRA}}{100} * \text{GW} * R,$$

where AR is the decided application rate, VRA is percentage value of the VRA task in current location, GW is ground water areas, current location is: inside polygon = 0, outside polygon = 1, R is rain, 0 is rain, 1 is no rain or no new data in the last 5 min.

The decision support rule is: if rain is expected within three

[1] http://www.postgresql.org.
[2] http://postgis.net.
[3] http://httpd.apache.org.
[4] http://tomcat.apache.org.
[5] http://geoserver.org.
[6] http://www.geonetwork-opensource.org.
[7] http://www.mapbender.org.
[8] http://www.opengeospatial.org.

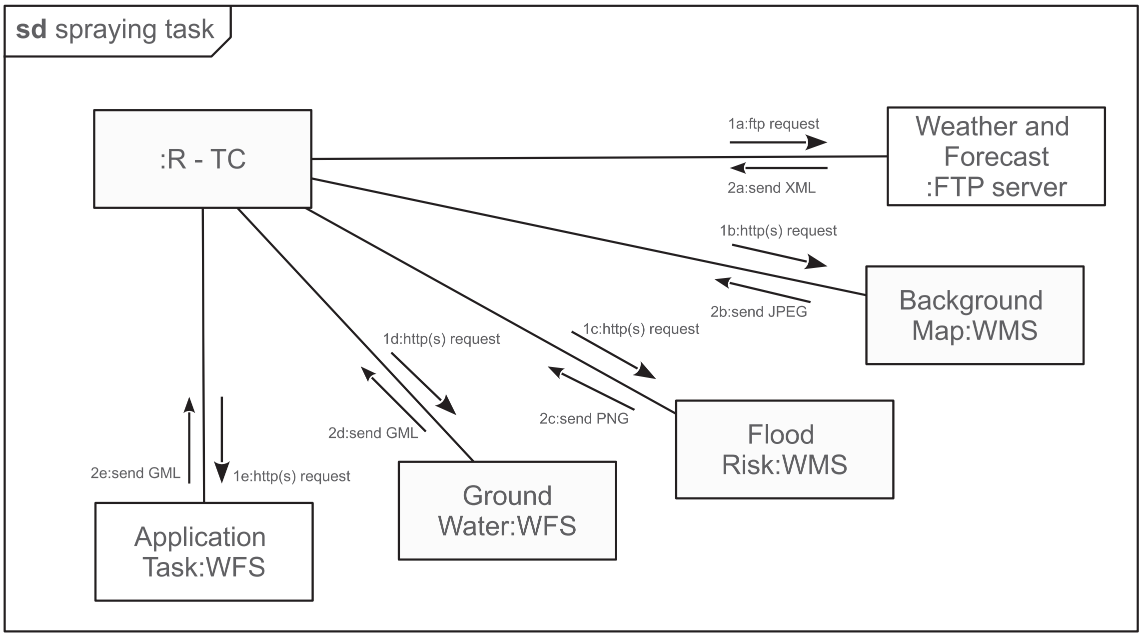

Fig. 1. Communication structure between the R-TC and the constructed services.

hours, the driver gets a visual warning. If it already rains, the VRA-output value is changed to 0%. In this study, we only used the wind and air temperature information as a visual guidance for the driver. A flow chart (Fig. 2) illustrates the requests that the R-TC does. Before the execution, the R-TC requests the predefined application task from the implemented server. Then the background ortophoto image from 2012 is downloaded in jpeg format from a WMS provided by Maanmittauslaitos using a GetMap-request. Then flood risk and groundwater areas are downloaded from the implemented service. During the work execution, the ground water boundaries are requested once in every ten minutes. For the weather, the R-TC is checking for updated parameters once in every 10 s.

The R-TC has six different screens, organised in tabulators. The tab TaskInfo is for downloading and checking the ISOBUS-task and GML-applications. DriveScreen (Fig. 3) is the main user interface when operating in the field. It shows the VRA task with a map as a background, the current VRA percentage, the risk of rain, wind speed and direction for the decision support, the status of tractor and CAN-bus, the driving direction and information about the current work rate and applied amount and the estimated status of the sprayer's tank. The FTP Server tab is used for setting up the communication to the weather server, the WeatherGraph tab is for the examination of the weather changes, the GroundWater tab shows the ground water areas similar to VRA-task and the final CAN + GPS Config tab is for monitoring and adjusting the hardware specific parameters.

The imported spatial information was published by the service according to the standards. Therefore machine could request the background map, the flood risk information, as well as the vector data of the application task and the groundwater boundaries. Inter-

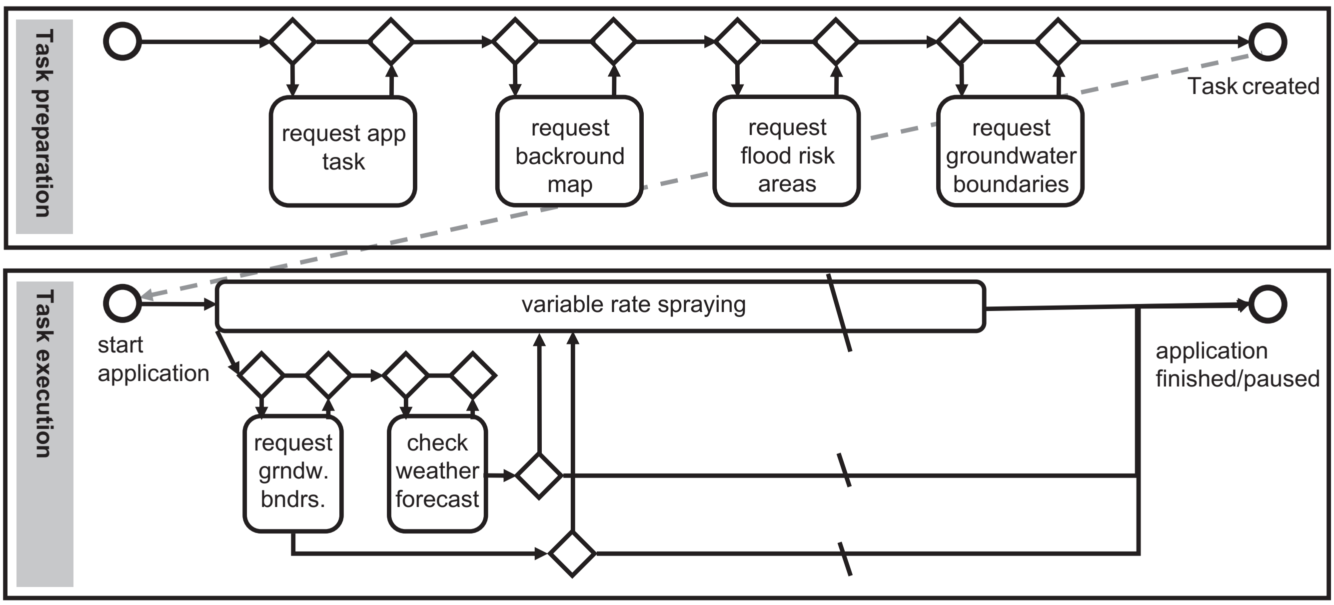

Fig. 2. A flow chart of the task controller.

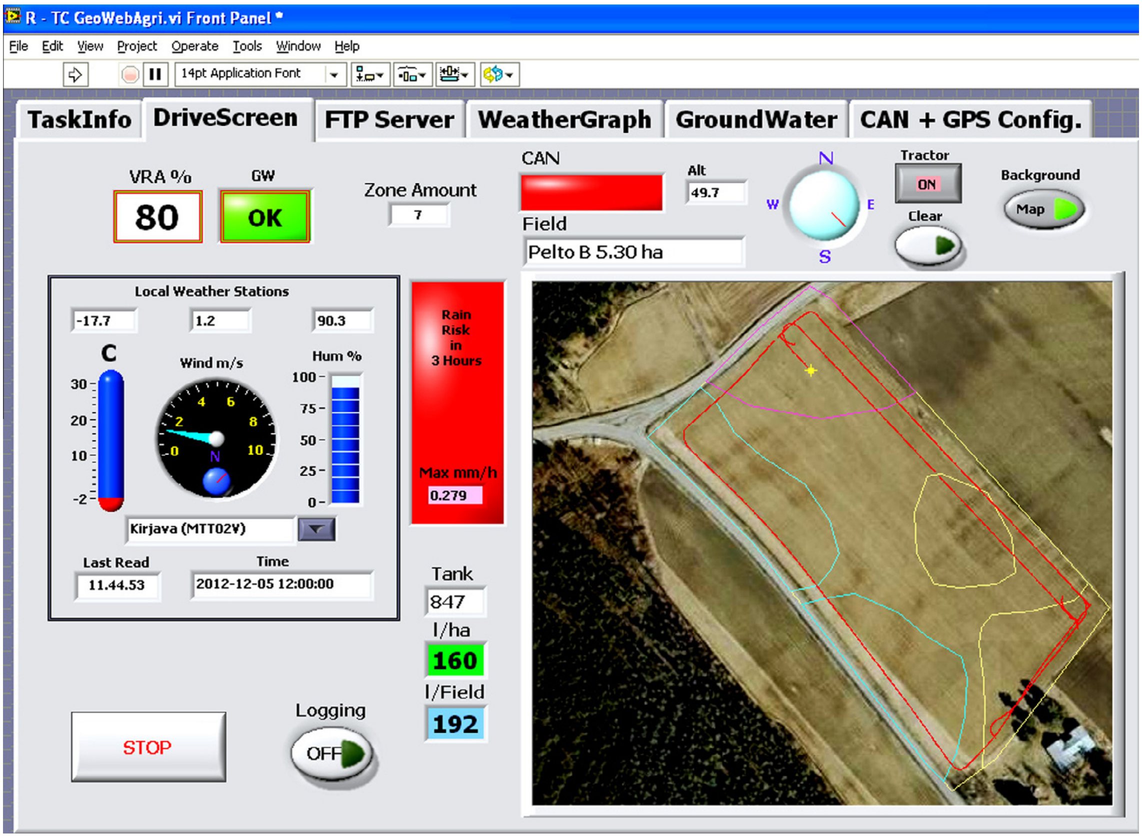

Fig. 3. User interface of the developed R-TC.

operability was implemented by the use of machine interpretable communication between database and task controller. The understanding of the semantic of the domain-overlapping data sets had to be programmed by humans to the control unit. Domain specific non automatic transferable vocabularies need adapted software interpretation.

The size of the GML task file with seven management zones was 15 kB. The size of ground water information file was 8 kB. The original size of the source shape file was 20 MB and 52 MB when converted to the GML. The size of XML weather data was 2.4 kB.

4. Discussion

We constructed a system that integrated external data from different sources to the TC on the tractor. The presented solution worked flawlessly and the required data transfer amount was rather small. We used available, existing data sets, focusing on a feasibility study for the interfaces and SDI components. Enabling GML formats and the usage of WFS in the ISOBUS-environment is the basis for the development of multiple tools for farming system development and practical environmental management. This paper did not evaluate how good or important this kind of web service implementation could be. That will depend on the quality and the accuracy of the source data and on the procedures used when reacting on the changing information. We presented a concept how to improve especially temporal accuracy in decision making during the field operation. Various types of data could be utilized. Some examples of beneficial data sources are listed below:

- Onboard sensors.
- Weather and forecast (rain, wind, temperature, heat sum).
- Disease pressure information.
- Sensitive environment (ground water, neighbouring plants and crops).
- Other external risks (flood, fire).
- Real time remote sensing (UAV, satellites, aerial images, other working units).
- Machine parameters (local measurements and calibrations of vehicle and implements)
- Other location based services (LBS) (e.g. neighbouring information).
- The work of other working units.

Using the presented method, the computations were done on the TC during the field operation and decisions were derived for optimized management. This could potentially overload the TC in terms of the computational power necessary. With the future integration of additional local computer systems or WPS (Web Processing Services) and cloud computing that possible problem is expected to be solved. Some beneficial and adaptable WPS tools have already been developed. Heier and Kiehle (2006) developed a WPS method for buffering calculation. Nash et al. (2007, 2009a) introduced an automatic processing of nitrogen fertilization application maps. Yang et al. (2012) deployed a WPS based geospatial processing framework in a cloud computing platform (AWS, 2009) and applied it to calculate the Normalized Difference Vegetation Index (NDVI) values for monitoring crop condition.

The dependability of a network connection during the field operation should always be very low. For the external data sources used in this study, data from WFS and WMS can be requested only once. Sufficient network connection availability similar to the task downloading with present solutions is required. Real time data was only used for as supporting information. The lack of real time data such as weather information did not prevent the work execution.

The experiments have shown the advantages of well-defined communication of software components via standardised (OGC) interfaces. Although we used an SDI approach, difficulties appeared in the interpretation of domain-overlapping data sets since the semantics of the data content could not be automatically interpreted. It led into a situation where the identification of object-data meaning in the SDI had to be done by humans. This happened because there was missing an abstracted data description language which would be interpretable by machines. The attributes had to be manually chosen from the geodata sets and were used in the processing according to their meaning which was only implicitly given. The semantics were derived from the metadata and name (which was language-dependent). This is preventing current systems to find and use suitable data sets automatically and solve a given task fully automatically.

For the ISOBUS standardization, this kind of task execution would require major changes. First, the OGC-related standards as the map format should be enabled and second, the TC should be able to fuse multiple tasks to a single command as presented.

5. Conclusions

This research presented a technical solution to integrate multiple external data sources like WFSs into the task execution process outlining a dynamic application task for precision agriculture. The shown methods can easily be used to adopt many other data sources with spatial or non spatial extent like agronomy specific rules presented by Nikkilä et al. (2013). With rather small amount of data, spatial and/or temporal information can be integrated into the automatic or supported decision making during the work execution.

More and more spatial data sources from many different providers become available via the web enabled geodata interface standards as used in this study. Automatic operational control emphasizes the need for available vector data. Farm machinery standardisation and FMIS software components should support them. The farm economics and environmental management will benefit most from these since there is a necessity of an optimised precision application.

There is still a need to be able to automatically interpret the semantics of data. This could be done with a well-defined categorization of data (e.g. object catalogues). A common catalogue with formalized semantic descriptions should be developed and defined for the agricultural domain. This can be done by applying ''Geographic information – Conceptual schema language'' (ISO-19103) and ''Geographic information – Rules for application schema'' (ISO-19109). These are the standards to formalize the domain-knowledge, leading to a machine-readable semantic for the objects and their structure. If such descriptions exist for the agricultural domain and its entities, data exchange and further automation can be achieved. Additionally, the exchange of data with other domains is profitable, when their semantics is clearly defined.

Acknowledgements

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Chapter 4

A Sensor Web-Enabled Infrastructure for Precision Farming

Geipel, J., M. Jackenkroll, M. Weis and W. Claupein, 2015. A Sensor Web-Enabled Infrastructure for Precision Farming. ISPRS International Journal of Geo-Information, 4(1):385-399.

UAV brought a new view to agriculture by offering comparatively fast and cheap measurements to the field. They established themselves in the market of sensor-platforms for PF and complement stationary, hand-held and machine-mounted sensors. Similar to the data exchange, normally the sensors are part of closed systems, which are offered in one package by the vendor. The systems lack openness. A solution for this weakness of PF solutions are standards for spatial information. For sensor technologies, there is the Sensor Web Enablement (SWE). This standard is focusing on sensor networks and includes a further standard, the Sensor Observation Service (SOS). Thus belonging to the sensor web layer, which is a standardized view on the sensors' measurements and data, offering an interface for user applications. After a sensor integration is done, the handling of data is standardized, as it happens in a coordinated infrastructure.
Designed for openness and re-use, the infrastructure, developed as a sensor integration layer, contains interfaces, which follow the principles of standardization. The Extensible Messaging and Presence Protocol (XMPP) is made for chat communication and can be used on private servers. Such an infrastructure was build up for the sensor platform-to-server data-transfer. In an experiment, on-the-fly data were transferred from the UAV to the ground and integrated into a sensor web. Thereby the data were accessible in a standardized way. FMIS, supporting these well-known interfaces, could integrate them and make them usable for the farmer.
The research presents an example, which overcomes closed components in the use of PF-operations. Thereby the field of static datasets was left behind, and real-time data has been integrated into the processes. A special characteristic is the implementation of a flying sensor platform.

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Article

A Sensor Web-Enabled Infrastructure for Precision Farming

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Abstract: The use of sensor technologies is standard practice in the domain of precision farming. The variety of vendor-specific sensor systems, control units and processing software has led to increasing efforts in establishing interoperable sensor networks and standardized sensor data infrastructures. This study utilizes open source software and adapts the standards of the Open Geospatial Consortium to introduce a method for the realization of a sensor data infrastructure for precision farming applications. The infrastructure covers the control of sensor systems, the access to sensor data, the transmission of sensor data to web services and the standardized storage of sensor data in a sensor web-enabled server. It permits end users and computer systems to access the sensor data in a well-defined way and to build applications on top of the sensor web services. The infrastructure is scalable to large scenarios, where a multitude of sensor systems and sensor web services are involved. A real-world field trial was set-up to prove the applicability of the infrastructure.

Keywords: Sensor Web Enablement; Open Geospatial Consortium; precision farming; interoperable; open source; 52° N; sensor; UAS; web service

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1. Introduction

The use of sensor technologies is more and more applicable in agriculture nowadays. In the domain of precision farming (PF), it is an inevitable aid for the generation of site-specific spatial and temporal information to support crop management strategies [1–3]. Within the last decade, several agricultural machinery and sensor construction companies have established a multitude of sensor systems for sensing soil- and plant-related parameters, as well as for sensing environmental impact factors, influencing the development of the cultivated plants [3]. Most of these sensor systems are designed for: (i) stationary use, e.g., soil moisture sensing networks [4,5]; (ii) hand-held use, e.g., fluorescence and hyper-spectral reflection sensors [6]; or (iii) mobile use on ground-based sensor platforms, e.g., fluorescence, hyper-spectral reflection and ultrasonic sensors, which are mounted on tractors [7–10]. Recent development added the possibility for (iv) mobile use on aerial sensor platforms, e.g., camera systems, which are mounted on unmanned aerial vehicles (UAVs) or unmanned aircraft systems (UASs) [11–13].

Most of these sensor systems are operated with vendor-specific control units, user interfaces and communication protocols. As this varies from sensor system to sensor system, using sensors from different vendors may quickly lead to complex, inconsistent and time-intensive procedures for sensor data storage, processing and distribution. Moreover, many sensor systems are integrated into decision support systems for site-specific online and offline applications and are implemented on tractor terminals, e.g., the Yara N-Sensor (Yara International ASA, Germany) and the GreenSeeker (NTech Industries Inc., Ukiah, CA, USA). Raw data access is not guaranteed in all circumstances, and users are commonly bound to vendor-specific processing routines in order to retrieve and analyze the collected sensor measurements.

To overcome this lack of standardized procedures for sensor control and access, as well as for sensor data encoding and distribution, Nash *et al.* [14] suggest utilizing standards from the Open Geospatial Consortium's (OGC) initiatives to automate agricultural sensor data processing. The OGC Sensor Web Enablement (SWE) initiative bridges the gap between sensors and processing applications, providing a suite of standards "[...] to enable all types of Web and/or Internet-accessible sensors, instruments, and imaging devices to be accessible and, where applicable, controllable via the Web" [15]. It consists of several definitions of "sensor related data in a self-describing and semantically enabled way" [16]. SWE, therefore, can be utilized as the basis for a sensor web, an infrastructure that hides the underlying architecture, the network communication mechanisms and the heterogeneous sensor hardware from the applications built on top [17]. Although most realizations of a sensor web originate in other fields of research and for large-scale scenarios, e.g., oil spill disasters [18], flood management [19] or general risk management [20], recent studies proved the adaptability for the agricultural domain, operating in even smaller contexts [21].

The first implementations for stationary wireless sensor networks (WSNs) proved the potential of this idea for precision agriculture. Some researchers describe improved concepts for decision making processes in agriculture by connecting WSNs with web services as part of a spatial data infrastructure (SDI), building on the SWE specifications [22–24]. Other researchers developed applications, based on these web services, e.g., for online spraying operations, utilizing a web feature service (WFS) on-the-fly [25]. Having a magnitude of possibilities to combine stationary and mobile, ground-based and aerial, as well as temporary and permanent sensor systems, current sensor networks have become more and more complex. As a consequence, the connection of sensor systems and entire sensor networks with a sensor web needs to be as flexible as possible to facilitate the integration of sensor data into web services and applications.

This study provides a simple, but effective method to embed various sensor systems into a sensor web approach, making their data accessible for applications using well-defined and interoperable standards of the OGC SWE initiative framework. The idea for establishing this method originates from the various field experiments, which were conducted at the agricultural research stations of the University of Hohenheim, Stuttgart, Germany. Many of these experiments involve sensor measurements, but lack a general work flow with standardized mechanisms for the control and access of sensors, as well as the storage and processing of their data. The authors show how to utilize open source software, provided by the 52° North Initiative for Geospatial Open Source Software GmbH (52° N), and adapt it to the needs of PF. A field trial environment was set-up to verify the method in a real use-case scenario for the adoption of SWE for PF-sensing.

2. Materials and Methods

This section gives background information about the principles and the implementation of an actual agricultural sensor infrastructure. The focus was set to publish sensor data to a remotely-distributed SWE infrastructure and make it accessible for researchers and user applications in a well-defined way. The sensor infrastructure of this study was based on the recommendations of Bröring *et al.* [18], who described the implementation of an extended sensor infrastructure stack. The infrastructure stack is shown in Figure 1 and will be explained in the following.

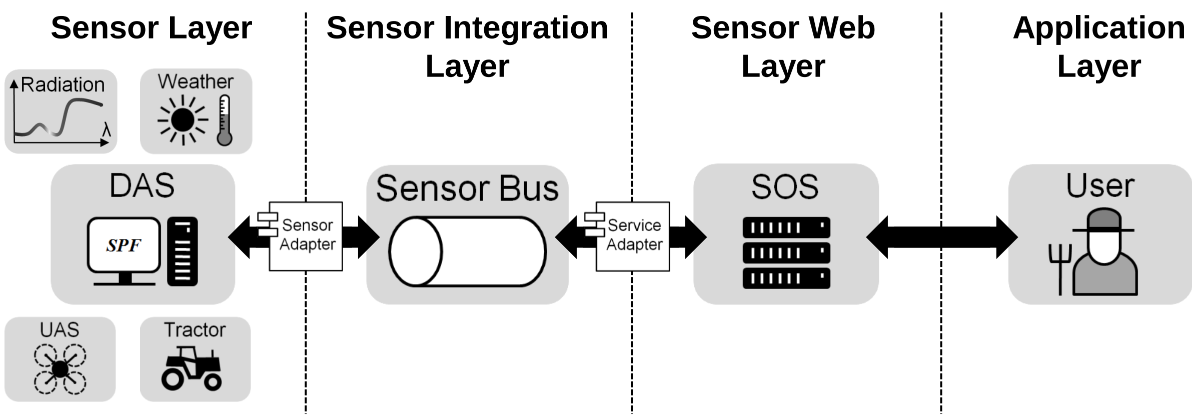

Figure 1. The extended sensor infrastructure stack as introduced by Bröring *et al.* [18]. It is based on three main layers for: (i) sensor control and communication (sensor layer); (ii) Sensor Web Enablement (SWE) services as part of a sensor web (sensor web layer); and (iii) end users and computers (application layer), which build applications on top of the SWE services. A fourth layer is an intermediary integration layer, facilitating the connection of sensors and services (sensor integration layer).

The extended sensor infrastructure stack is based on three main layers and one integration layer, covering all levels from sensor measurements to end-user applications. The sensor layer is the lowest level layer, managing the communication within sensor networks. It consists of the different sensor devices and one or several data acquisition systems (DAS), to control and access all sensor systems on-the-fly. The sensor integration layer is an intermediary layer between sensors and SWE services. Its idea is to establish an infrastructure that connects sensor web services, requesting specific sensor data, with sensors, delivering exactly the requested data, on-the-fly [26]. The sensor web layer consists of one or a multitude of SWE services. Each service is defined for special purposes, e.g., the sensor event service (SES), which offers a web interface to publish and subscribe to notifications from sensors [27], or the sensor observation service (SOS), which offers the discovery and retrieval of real-time or archived data, produced by any kind of sensor system [28]. The application layer is the highest level layer, where users or computer systems interact with the SWE services.

This study proposes an infrastructure that consists of a sensor layer, a sensor integration layer and a sensor web layer. An application layer was not part of this study. The following paragraphs give insight into the implementation of these layers.

2.1. Sensor Layer

The sensor layer represents the lowest level layer of the proposed infrastructure. It was set-up by four different sensor systems and a DAS, to control and access the sensor systems. Communication was enabled by a 2.4-GHz wireless local area network (WLAN) and a 3G mobile Internet connection.

2.1.1. Sensor Systems

The sensor layer involved: (i) a stationary HYT221 weather sensor (HYT221, IST AG, Wattwil, Switzerland) for measuring temperature and relative humidity; (ii) a stationary MMS1 NIR enhanced spectrometer (HandySpec Field, tec5 AG, Oberursel, Germany) for the registration of incident solar radiation; (iii) a tractor, equipped with a Multiplex fluorescence sensor (Multiplex, FORCE-A, Orsay, France) for the detection of within-field plant health; and (iv) Hexe, a prototype UAS, equipped with a PiCam RGB camera (Raspberry Pi Camera, Raspberry Pi Foundation, Caldecote, Cambridgeshire, UK), a self-assembled multi-spectral camera (D3, VRmagic Holding AG, Mannheim, Germany) and an MMS1 NIR enhanced spectrometer, for the detection of plants' spectral parameters [29]. The HandySpec sensor system was operated by a consumer notebook, which also served as the processing unit for the DAS. All other sensor systems were operated by individual Raspberry Pi Model B computers (Raspberry Pi Foundation, Caldecote, Cambridgeshire, UK), which were equipped with wireless adapters to enable communication with the DAS (see Figure 2).

All sensor systems were geo-referenced. The stationary sensor systems were placed at well-known locations, whereas the mobile platforms were equipped with a Global Navigation Satellite System (GNSS) to track their locations on-the-fly. The sensors were controlled by self-developed software routines, implementing vendor-specific application programming interfaces (APIs). The software routines were executed on the Raspberry Pi control units and the notebook.

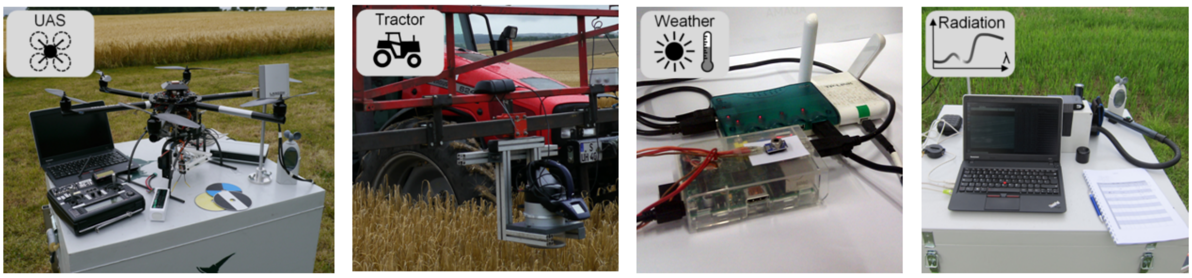

Figure 2. Overview of the sensor systems involved in the sensor layer. From left to right: Hexe (unmanned aircraft system (UAS)), Multiplex fluorescence sensor (tractor), HYT221 weather sensor (weather) and HandySpec Field spectrometer with base station (radiation).

2.1.2. Data Acquisition System

As DAS software, the authors chose the java-based and open source software framework "Sensor Platform Framework" (SPF, https://wiki.52north.org/bin/view/SensorWeb/SensorPlatformFramework). Its main purpose is to gather and, if needed, interpolate sensor data based on a periodic time interval or the availability of certain observations. Its generic architecture supports the inversion of control (IoC) design, offering extension points, which act as interfaces for input and output plugins [30].

Every connection of a sensor system with the DAS was realized by implementing an individual input-plugin and a plugin description document. As all sensor control units and the DAS share the same network, the input-plugins were configured: (i) to establish a network connection to the appropriate sensor control unit; (ii) to send configuration parameters; and (iii) to request sensor observations (see Figure 3).

The plugin description document describes the plugin's interpolation behavior, the sensor's observations and its meta data. The meta data were encoded in SensorML, a sensor description language, which is specified by SWE and used to describe sensors and processes [31]. Table 1 lists the most important parameters of each input plugin.

On the output plugins' side, three output mechanisms were of interest: a visual control of the geo-referenced sensor observations, a mechanism to forward the sensor observations into the sensor web and a simple data logger in case the DAS is disconnected from the sensor web. All of these mechanisms have already been established in three different output plugins, which can be downloaded from the 52°N website and are displayed in Figure 3. Visualization was done by the "SensorVis—Real Time Sensor Visualization" (https://wiki.52north.org/bin/view/SensorWeb/SensorVis) plugin, which allows live visualization of sensor data based on a 3D virtual globe environment [32]. Logging was realized using a slightly adapted version of the "File Writer Plugin", which is part of the standard SPF packages. As the forwarding mechanism, the "Sensor Bus Output Plugin", also distributed within the standard SPF packages, was used. It implements a sensor adapter for a logical bus for the standardized connection of sensor data and SWE services, which will be explained in the following paragraphs [18,26].

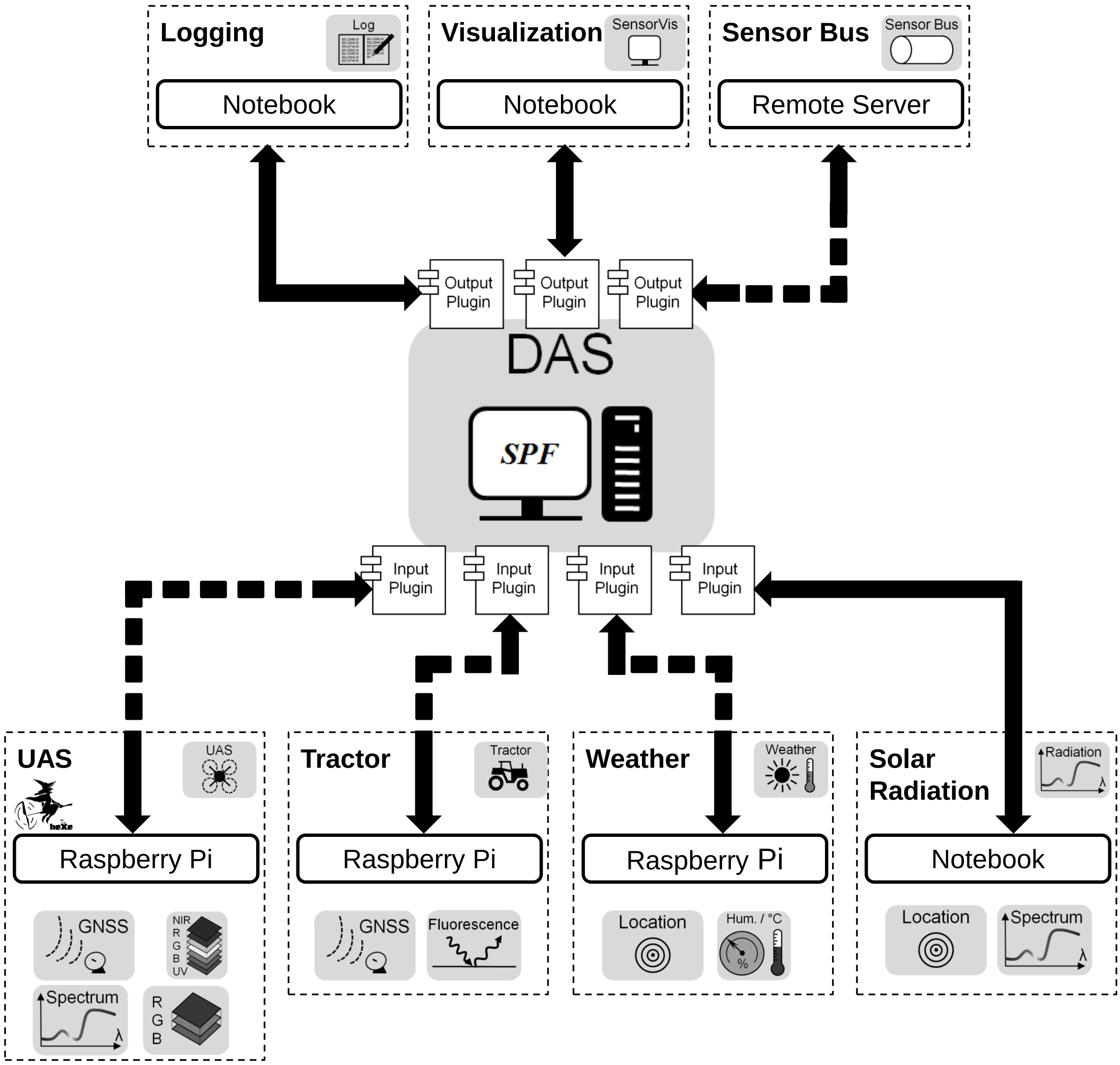

Figure 3. Overview of the input and output plugin architecture of the Sensor Platform Framework (SPF), which serves as the data acquisition system (DAS). Four input plugins were implemented to control and access all sensor systems individually. The Raspberry Pis and the notebook serve as control units, implementing vendor-specific sensor protocols. DAS and control units communicate with each other either through wireless (dashed lines) or wired connections (solid lines). Three output plugins were implemented for: (i) the live-visualization of sensor observations during measurement; (ii) for the local logging of received sensor data; and (iii) for the forwarding of the sensor data into the sensor bus. Visualization and logging were performed on the notebook, running the DAS. Forwarding data into the sensor bus was realized via a mobile Internet connection.

Table 1. Summary of the the sensor systems' observations, specified in the input plugins.

Sensor System	Sensors	Observations
Hexe	GNSS	Lon, Lat, Alt
	IMU	Nick, Roll, Yaw
	MMS1 NIR enhanced	256 reflection values
	PiCam RGB	Image identifier
	VRmagic Camera	Image identifier
Tractor	GNSS	Lon, Lat, Alt
	Multiplex	6 fluorescence indices
Weather	Preset location	Lon, Lat, Alt
	HYT221	Relative humidity
		Temperature
Solar Radiation	Preset location	Lon, Lat, Alt
	HandySpec	256 radiation values

2.2. Sensor Integration Layer

The authors chose the sensor bus to serve as the sensor integration layer in between sensor systems and remotely-connected sensor web services (see Figure 4). Although it is designed to enable a sensor plug and play infrastructure for a sensor web by incorporating semantic matchmaking functionality, a publish/subscribe mechanism and a generic driver mechanism [18], the available sensor bus output plugin is limited to messaging, based on the sensor bus protocol [26]. Therefore, matchmaking, publish/subscribe and driver issues were handled manually.

A driver mechanism to control and access the connected sensors was implemented for every SPF input plugin, individually. The sensor bus plugin was configured to publish all sensor data, gathered by the SPF, into an Extensible Messaging and Presence Protocol (XMPP) chat channel, which ran as ejabberd (https://www.ejabberd.im) software on an Internet-connected server at the University of Hohenheim (see Listing 1). The chat message format follows the sensor bus protocol specifications and offers a simple solution to distribute sensor data to a remote SWE service.

A sensor bus service adapter was implemented to forward the observations from the sensor bus to an SOS. It was realized as a python program. It subscribed and listened to the XMPP chat channel, which contained the published sensor data (see Listing 1). The service adapter was designed to parse the sensor data from the sensor bus protocol format to an SOS request Extensible Markup Language (XML) format. Related sensor observations were assembled and grouped following the predefined SensorML profiles. Subsequently, an *InsertObservation* request was composed to add the observations to the SOS [28]. The *InsertObservation* request is part of the transactional operations SOS profile. This optional transactional profile allows clients to register new sensors (*InsertSensor*) and add observations. Observations in the request are encoded in accordance with the Observations and Measurement (O&M) schema, a standard to describe all observations of a sensor system [33].

Listing 1: Exemplary listing of a sensor bus message, published by the HYT221 weather station. The sensor adapter broadcasts a message to register the sensor (*SensorRegistration*) and publishes all available sensor observations (*PublishData*), consequently.

```
(10:11:58) spf_user2: SensorRegistration>urn:sengis:id:HYT221>urn:sengis:id:HYT221 (stationary platform) connected via SPFramework>
urn:sengis:id:HYT221>
firstCoordinateName<latitude<secondCoordinateName<longitude<thirdCoordinateName<altitude>urn:ogc:def:crs:EPSG::4326>0.0>0.0>0.0>
humidity<%<altitude<m<longitude<deg<latitude<deg<temperature<Cel>SensorRegistration
(10:11:58) spf_user2: PublishData>urn:sengis:id:HYT221>2014−06−27T10:11:57.355+01:00>class java.lang.Double>36.2>humidity>
(10:11:58) spf_user2: PublishData>urn:sengis:id:HYT221>2014−06−27T10:11:57.355+01:00>class java.lang.Double>485.234>altitude>
(10:11:58) spf_user2: PublishData>urn:sengis:id:HYT221>2014−06−27T10:11:57.355+01:00>class java.lang.Double>8.9221>longitude>
(10:11:58) spf_user2: PublishData>urn:sengis:id:HYT221>2014−06−27T10:11:57.355+01:00>class java.lang.Double>48.7450>latitude>
(10:11:58) spf_user2: PublishData>urn:sengis:id:HYT221>2014−06−27T10:11:57.355+01:00>class java.lang.Double>18.54>temperature>
```

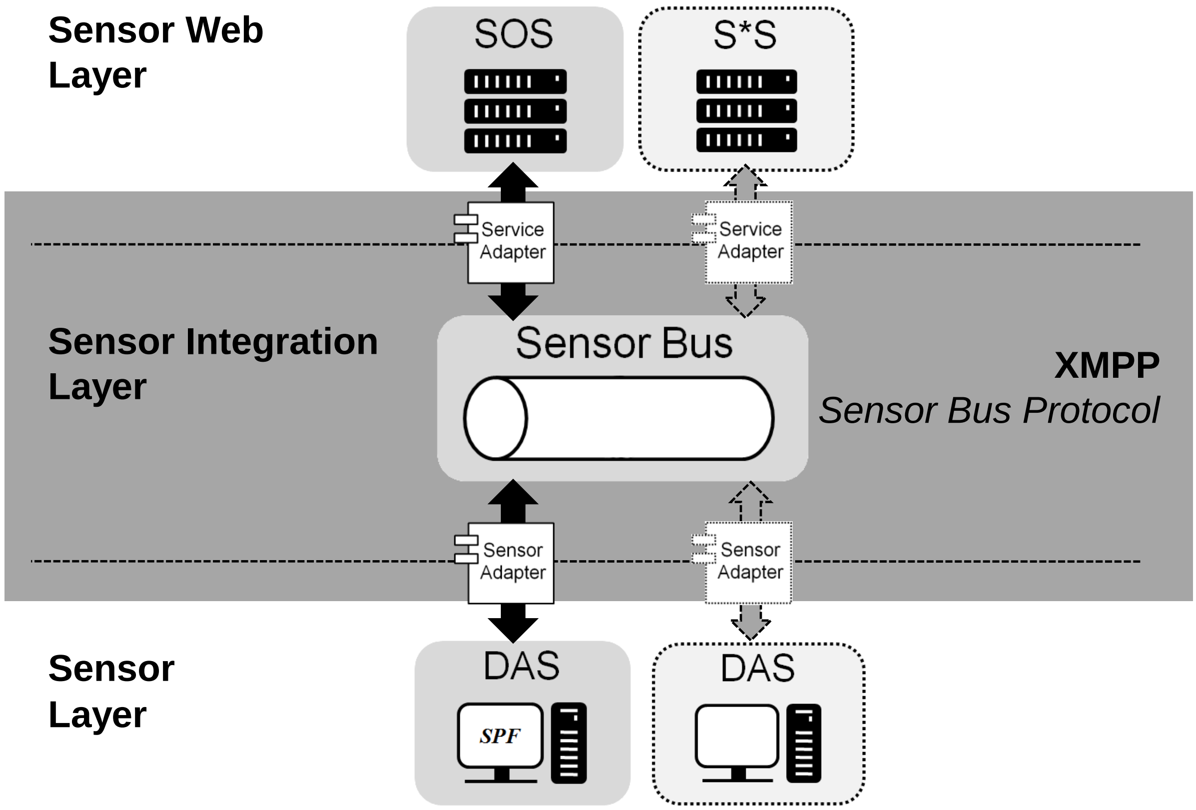

Figure 4. Overview of the sensor bus architecture, which is designed to facilitate the communication of sensor systems and SWE services. Any kind of sensor adapter can register to the bus and publish its sensor data according to the sensor bus message protocol. For subscription and receiving of sensor data, any kind of SWE services can register a service adapter, listening to the sensor bus. The architecture is scalable to scenarios where a multitude of sensor systems and SWE services participate.

2.3. Sensor Web Layer

The sensor web layer consists of an SOS. It is the most common SWE service and it was used in this study in its 52° N SOS 4.1 (https://wiki.52north.org/bin/view/SensorWeb/SensorObservationServiceIV) implementation, exclusively. It was set-up on a server, running at the University of Hohenheim. It offers a web interface for publishing operations, e.g., *GetCapabilities*, *GetObservation* and *DescribeSensor*, on the one hand, and for transactional operations, e.g., *InsertSensor* and *InsertObservation*, on the other hand. It builds on the technical frameworks of an Apache Tomcat 7 (http://tomcat.apache.org/tomcat-7.0-doc) servlet container, a PostgreSQL 9.3 (http://www.postgresql.org/docs/9.3) Database Management System (DBMS) and a PostGIS 2.1 (http://postgis.net/2013/08/17/postgis-2-1-0) support for geographic objects.

Based on the SensorML descriptions of every input plugin, each sensor system was registered once using the *InsertSensor* operation. After having registered the individual sensors, the sensor bus service adapter was able to perform *InsertObservation* operations on-the-fly, using the Service-Oriented Architecture Protocol (SOAP).

2.4. Field Trial

A typical PF field experiment served as test-bed for the proposed infrastructure. The field trial was conducted on 27 June 2014 and in clear skies in a field of winter-wheat (*Triticum aestivum* L.), located at Ihinger Hof (48.74°N, 8.92°E), a research station of the University of Hohenheim. The trial's aim was the acquisition and storage of sensor observations: (i) locally, on a notebook, running the DAS; and (ii) remotely, on an Internet-connected SOS.

The sensor systems were mounted on ground, on a tractor and on a UAS. The tractor and the UAS were configured to follow a predefined route in the field, whereas the weather station and the solar radiation sensor were set-up at fixed locations at the field's border. The consumer notebook, running the DAS, was set-up at the solar radiation sensor's location, together with a 2.4-GHz WLAN access point and a 3G mobile Internet connection, realized by mobile phone tethering. All sensor systems were operated simultaneously with a sampling interval of 1 Hz during a measurement period of approximately 6 min. Observation pull-requests were performed at the same rate via the 2.4-GHz WLAN connection. A maximum distance of 180 m in between the sensor system and notebook was reached by the UAS. The UAS covered a total area of 180 $\times$ 36 m.

Visualization and logging of the received observations took place on the notebook. Moreover, broadcasting was performed by the sensor bus plugin via the mobile Internet connection. The sensor bus messaging infrastructure was implemented as an ejabberd XMPP service on an Internet-connected server at the University of Hohenheim. In addition, this server hosted the SOS, as well as the sensor bus service adapter, which was listening to incoming messages of the XMPP chat channel. Figure 5 gives an overview of the complete infrastructure with a UAS observation example.

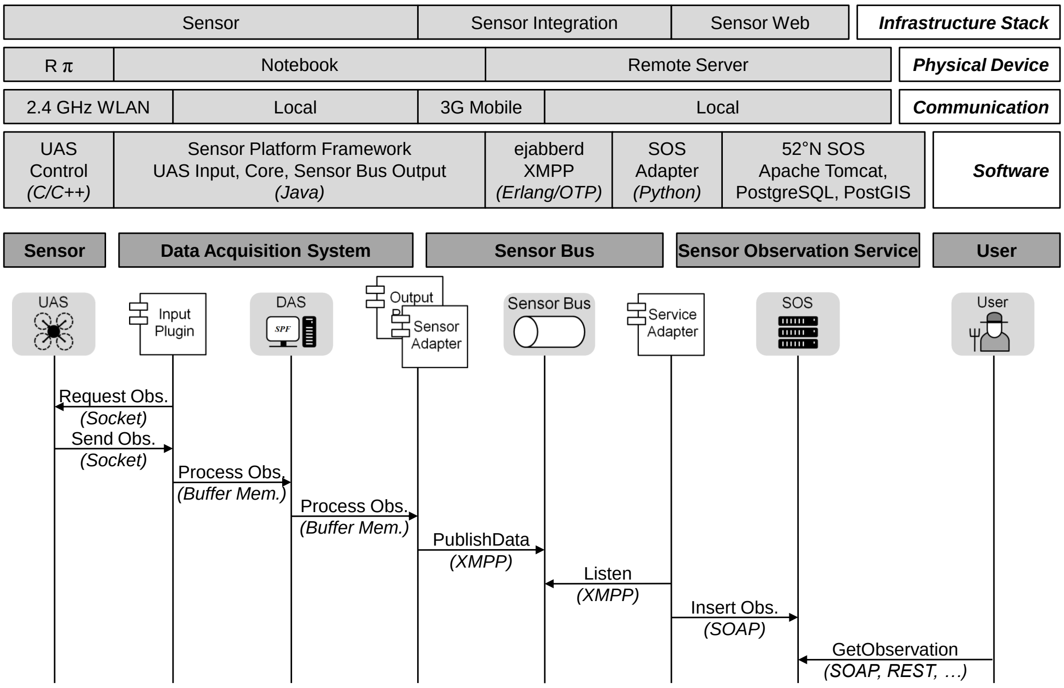

Figure 5. Sequence diagram of the processing of an exemplary UAS observation from acquisition to storage on an Internet-connected SOS (lower half). The upper half gives information about the realization of the different components of the infrastructure.

3. Results and Discussion

The infrastructure proved its ability to control all sensors, to access and forward their data and to store them in a well-defined, standardized SOS. The field trial showed that this sensor infrastructure is applicable to PF scenarios, although some hurdles still exist.

3.1. Sensor Layer

Despite having two connection losses of approximately 10 s due to instabilities of the WLAN, the sensor layer behaved as expected. Under stable network conditions, all sensor systems could be controlled flawlessly. Their data could be accessed by the DAS and forwarded to the sensor integration layer. The mobile Internet connection was stable throughout the whole test.

Intensive work had to be invested in the programming of the control unit software of all sensor devices. The software was designed to keep the sensors remotely controllable and accessible via network socket communication. Every software implementation had to cope with sensor-specific drivers and protocols. Although most sensor vendors offer APIs for software developers, some sensor protocols still have to be implemented by one's self, e.g., the Spectral Device Control and Transfer Protocol (SDCTP) for network control of the MMS1 NIR enhanced spectrometer. A generic driver mechanism, e.g., the sensor interface descriptor (SID) model, could overcome this intensive labor [34].

The SPF, which was used as DAS, served its purpose to integrate all sensor systems. Nevertheless, implementing correct input plugins and plugin descriptions had to be done carefully. Each input plugin was programmed to connect to a specific network socket to communicate with its according sensor control unit. Sensor data access was implemented with 1-Hz pull requests, which worked reliably, apart from two times of network instability. For configurable sensors, sensor control was realized via a graphical user interface (GUI). Sensor descriptions were realized in a standardized way with SensorML, defining the sensors' characteristics as part of a plugin description document. Moreover, the description document was used to specify the input plugins' interpolation behavior, as well as the input and output of observations. The output plugins worked as expected. Once registered for use, the visualization plugin was able to display all observations from every sensor on-the-fly (see Figure 6). The logging plugin logged all incoming observations to a .csv file. The size of the .csv file summed up to 1.3 MB during 6 min of measurement. The sensor bus output plugin worked flawlessly. It parsed the incoming observations to the sensor bus protocol format and forwarded the data into the XMPP chat channel.

The sensor layer implementation proved its practicability. A stable network and Internet connection is essential for this architecture. Despite potentially missing some of the sensed data due to unpolled pull mechanisms, instabilities may be also critical for near real-time applications in scenarios where data acquisition, data processing and application are performed online.

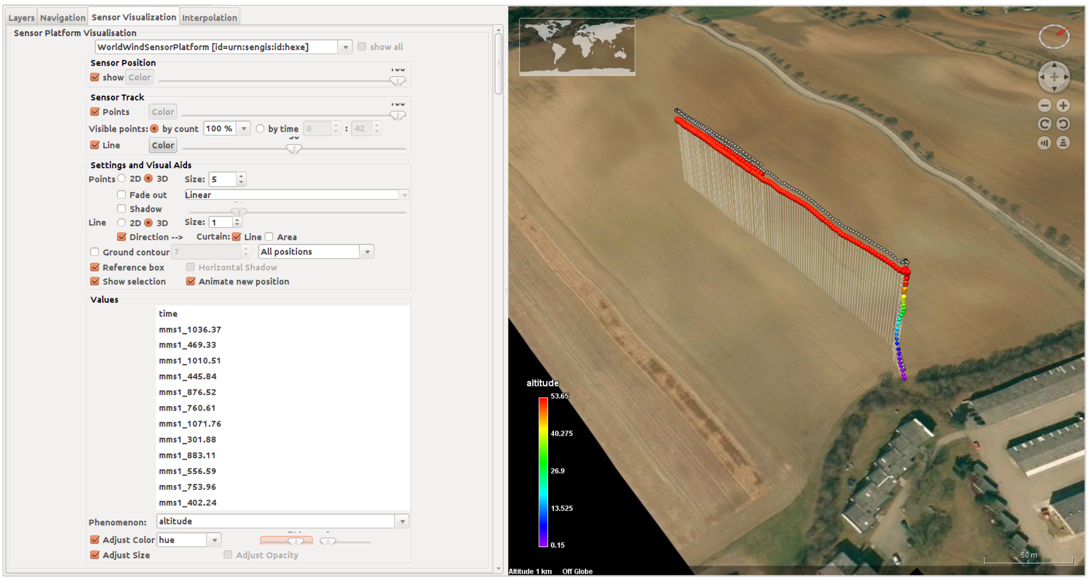

Figure 6. Example of the SPF "SensorVis" output plugin [32] live-visualization of Hexe, a UAS sensor system, operating during the field trial. On the left side, visualization parameters can be selected and configured, depending on the available sensor observations. On the right side, the flight path and the selected sensor observation values are visualized by colored spheres, *i.e.*, indicating the received flight altitude information.

3.2. Sensor Integration Layer

The sensor integration layer was restricted to the sensor bus messaging mechanism, due to the limited functionality of the sensor bus output plugin. It was able to connect to the chat channel and broadcast all sensor data, collected by the DAS. Instead of broadcasting complete raster datasets, e.g., images, the captured raster data description was restricted to short image identifiers. As a consequence, all sensor datasets could be transmitted through the wireless Internet connection. The data transfer to the XMPP service was not encrypted. Generally, transfer encryption is desirable and available (transport layer security, TLS). If the channel communication should be kept private, it can be restricted to certain users and password authentication.

As this study utilizes only one sensor adapter and one service adapter, the sensor bus architecture is not exploited in all of its possibilities. Nevertheless, the introduced infrastructure offers the scalability of the sensor bus concept. It can be adapted to a multitude of sensor adapters and service adapters, e.g., for multiple SOS and SES, located at different institutions. Moreover, as it is a logical concept, messaging is not restricted to XMPP and can be replaced or extended by other communication protocols, e.g., Twitter and Internet Relay Chat (IRC) [18]. To enable sensor plug and play, mediating, publish/subscribe and driver mechanisms still have to be implemented.

3.3. Sensor Web Layer

The sensor web layer performed well. The Apache Tomcat server, as well as the PostgreSQL/PostGIS DBMS were installed smoothly, following the documented standard installation routines. The SOS package was delivered as a self-extracting file for the servlet container. The installation worked as expected. All needed databases were created automatically after SOS configuration. The SOS supported all operations of the implemented SOS service adapter. Here, *InsertSensor* and *InsertObservation* were used.

4. Conclusions

This work proved the applicability of the OGC SWE initiative framework definitions for the set-up of a sensor data infrastructure for PF applications. The proposed infrastructure guarantees a standardized collection and storage of spatio-temporal agricultural sensor data, accessible by SWE services and user applications. It is based on open source software, offering the possibility to deploy numerous sensor systems and SWE services. The DAS provides a consistent method for the control, access and forwarding of sensor observations. The sensor bus concept is scalable to more complex scenarios involving a multitude of sensor systems, DAS and SWE services. The implemented SOS is a first step towards a service-oriented architecture, based on further web services and OGC standards, offering functionalities of a holistic SDI for PF. In an SDI, web clients act as interfaces in between stored sensor data and a user, realizing the application layer of the infrastructure stack. It can be applied to machinery and sensor systems on the farm scale or be extended with data services offered by external parties. Moreover, as observations acquired by mobile or stationary systems share the same infrastructure, the applications and work flows built on top of it can themselves be built for mobile or stationary devices. Future research will be concentrated on establishing such an SDI for standardized sensor data distribution, processing and analysis in the PF domain.

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Author Contributions

Jakob Geipel and Martin Weis proposed the idea for this work. Jakob Geipel wrote the manuscript, and programmed the control units and the input plugins of the sensor layer. Markus Jackenkroll set up the server, the DBMS and the SOS of the sensor web layer. Martin Weis programmed the sensor bus service adapter of the sensor integration layer. Jakob Geipel, Markus Jackenkroll, and Martin Weis performed the field work. Wilhelm Claupein helped with editorial contributions.

Conflicts of Interest

The authors declare no conflicts of interest.

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Chapter 5

Optimizing precision agricultural operations by standardized cloud based functions

Jackenkroll, M., G. Peteinatos, B. Kollenda, R. Mink, R. Gerhards (2021). Optimizing precision agricultural operations by standardized cloud-based functions. Spanish Journal of Agricultural Research, 19(4), e0212.

Section 1 to 3 deal with the integration of data by standardized services into an agricultural SDI. Especially section 2 and 3 present approaches to improve the infrastructure by the enrichment of data in PA-operations. Simultaneously, there is research, which doubt the benefit from additional data in the process. Instead, Daróczi et al. (2013) recommends an improvement of the processes.
In geoinformatics the OGC WPS is designed for processes, especially for the treatment of spatial data. The standard offers an interface description for web access. By this, coded procedures could be used. A frontend, in which a WPS-option is integrated, could import all kinds of processes by the web and increase its functionalities. As an integrable web service, it could be used as a further level of specialization for the development of software as an expert, team or scientist of a specific topic, could offer one's individual solution.
The processing by a service offers another option. Outsourced to an external server, it follows the principles of cloud computing. It does not matter where the service is running. Also, the used calculation power, appropriate hardware assumed, can be regulated concerning the needs. Therefore, the use of WPS brings PA to distributed systems and the idea of FaaS.
The mentioned concept of using a WPS as a service-based function, is analyzed in two PA-use cases. Further it is realized in a UAV-image interpretation by a plant index and the ongoing calculation of an application map. Also, the option of integration into cloud technology and their use in PA is analyzed.

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RESEARCH ARTICLE

OPEN ACCESS

Optimizing precision agricultural operations by standardized cloud-based functions

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Abstract

Aim of study: An approach to integrate knowledge into the IT-infrastructure of precision agriculture (PA) is presented. The creation of operation relevant information is analyzed and explored to be processed by standardized web services and thereby to integrate external knowledge into PA. The target is to make knowledge integrable into any software solution.

Area of study: The data sampling took place at the Heidfeld Hof Research Station in Stuttgart, Germany.

Material and methods: This study follows the information science's idea to separate the process from data sampling into the final actuation through four steps: data, information, knowledge, and wisdom. The process from the data acquisition, over a professional data treatment to the actual application is analyzed by methods modelled in the Unified Modelling Language (UML) for two use-cases. It was further applied for a low altitude sensor in a PA operation; a data sampling by UAV represents the starting point.

Main results: For the implemented solution, the Web Processing Service (WPS) of the Open Geospatial Consortium (OGC) is proposed. This approach reflects the idea of a function as a service (FaaS), in order to develop a demand-driven and extensible solution for irregularly used functionalities. PA benefits, as on-farm processes are season oriented and a FaaS reflects the farm's variable demands over time by origin and extends the concept to offer external know-how for the integration into specific processes.

Research highlights: The standardized implementation of knowledge into PA software products helps to generate additional benefits for PA.

Additional key words: agricultural value chain; cloud computing; function as a service; precision agriculture; standardization; web processing service

Abbreviations used: API (Application Programming Interfaces); CAN (Controller Area Network); DIKW-model (data–information–knowledge–wisdom-model); DSS (Decision Support System); ExGR (excess green minus excess red index); FaaS (Function-as-a-Service); FMIS (farm management information system); GDPR (General Data Protection Regulation); http (hypertext transfer protocol); IoT (Internet of Things); ISOBUS (International Standardization Organization Binary Unit System); IT (information technology); OGC (Open Geospatial Consortium); PA (precision agriculture); PaaS (Platform-as-a-Service); RGB (red–green–blue); SOA (service-oriented architecture); UAV (unmanned aerial vehicles); UML (Unified Modelling Language); WFS (Web Feature Service); WPS (Web Processing Service); XML (extensible markup language).

Authors' contributions: Development of concept: MJ, GP, RG. Development of models and realization of infrastructure and web services: MJ. Gathering and processing of field data: RM, BK. Writing the original draft: MJ, GP, RM, RG.

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Introduction

Nowadays agriculture is highly mechanized and incorporates various sophisticated systems, technologies and sensors. For a successful agricultural practice, and in which one achieves the optimum result, it is imperative to establish the cooperation between the farmer and other actors, such as sensor and machinery manufacturers, chemical and ecological conductor vendors, relative advisory services and current knowledge and trends of the scientific community. An important aim of successful farming is to increase yield by modifying and optimizing the process to achieve the best possible environment, requiring the minimum effort, natural sources, and environmental load, while preserving and, if possible, increasing the product quality. Precision agriculture (PA), originally established in the 1980s has already delivered tools and technologies that are aiding agriculture. Satellite-guided systems, satellite-based data, spectral indices, drone data are readily available. Information technologies are pushing the development of new tools and ideas. Sensors are improving, while data gathering and transportation enable a better overview of the field. This result facilitates a more optimized field management and diversification. In moving towards that goal, data handling and relevant infrastructure need to be improved (Villa-Henriksen, 2020). Available data sometimes are not utilized, at least not to their full potential, due to the lack of integration means among different systems (Fulton, 2018). Hardware, software, data and services need to be established and incorporated in a unified environment.

The most distributed standard in agricultural field operations is the ISO 11783. The ISOBUS (International Standardization Organization Binary Unit System) was established as a unified communication protocol for tractors to implement and extend towards the farm management information system (FMIS). The tractor-implement system has been irreplaceable for the farmer. In addition to hardware-linkage, it defines the method, data-transfer format and user-interfaces. It designs the interface to the vehicle bus standard CAN (Controller Area Network). The relevance of ISOBUS has increased by the development of PA and the meaning of transparency with regards to agricultural production. In 2013, already 50% of tractor vehicles had the capability to be equipped with ISOBUS (Daróczi, 2013). In particular, for high-grade machinery it became a basic feature.

The widespread use of ISOBUS is an invitation and a deterrent at the same time. Its concept is powerful, but it is also complex. This complexity is expressed in the size of the belonging ISO 11783 standard, which consists of 14 parts. It is seldom realized to its full potential or specifications. The majority of implementations focus normally on their application. The integration of components on the machine, which do not belong to basic tractor equipment, is often insufficient. Even communication between different versions or generations of implements are often ambiguous. Integration, for example from additional field sensors, is a challenge for software developers. Concerning sensors, there is good implementation for established products (Paraforos *et al.*, 2019), but it might be hard to dock a new, innovative sensor and integrate its data into the information technology (IT)-system of the machine. Nikander *et al.* (2019) noticed an increasing number of farmers using software, but many of them work with printed operation maps in the field. The information chain from preparation at the desk by a farm management information system (FMIS) to the terminal screen is not seamless or trivial for farmers (Sørensen *et al.*, 2010). In particular, this is true when devices or software of different brands or ages have to interact. For several years, large sellers of machinery have offered web-based platforms for machinery data exchange. Wolfert *et al.* (2017) identified those as limited but observed a slow rethinking towards open data exchange by open Application Programming Interfaces (APIs). APIs might make big data analysis possible, as manufacturers noticed potential benefits from the agricultural value chain. A practical example is "Nevonex" (Robert Bosch GmbH, 2020), a platform including ISOBUS and non-ISOBUS devices by operation-oriented applications. Each feature on this platform offers individual functionalities, but also the option of exchange. It thereby makes the exchange of data from different PA components easier. Expandability becomes more straightforward, and it simplifies the development of new hardware and software.

The relevance of more information in field managing processes was evaluated by Dyer (2016), who explained this importance through the logic of better operations for more information. Furthermore, he gives an overview of efforts and strategies by companies into this field. On the other hand, Daróczi (2013) determinated that farmers could not benefit from additional data. Therefore, data have to be upgraded into operationally relevant information by procedures. External additional sources and sensors are themselves producing numbers without value. Further calculation (and knowledge) is needed to convert data into information about the situation at the location and time of measurement. This information might be useful for defining operations.

Daróczi (2013) recommended the interconnection and automation of processes in PA. Inspired by the work of Nash *et al.* (2009), who presented the idea of improving PA by integrating in it the standards of the Open Geospatial Consortium (OGC). Similarly, Kaivosoja *et al.* (2013) integrated the ISOBUS on the machine level by improving the functionality of the task controller using an OGC Web Feature Service (WFS). In doing so, the well-developed data handling of geoinformatics is connected to the standards of PA. The WFS-standard is one of the OpenGIS web services of the OGC. Among other OGC services the OGC Web Processing Service (WPS) is the service description for the realization of processing in a standardized way, implying the knowledge and logic of data processing.

Standardization makes integration into software solutions possible with low effort. Existing systems could be expanded by a WPS-interface, visible for the user or hidden behind the functionality of a software solution. As a service could be integrated into every service-oriented architecture (SOA), a desktop-based software, a web-client or a mobile app could interpret the WPS-logic and increase operation-range and -density.

Regarding the internet of things (IoT), processing of sampled data has a central meaning for future development, as the storage of data is not equal to an added value, rather it is information created from these data by processing by requests via hypertext transfer protocol (http) and responses in extensible markup language (XML). It was designed for geospatial applications but could be used for the processing of non-spatial data as well (Müller, 2018).

Kraatz *et al.* (2015) presented a use-case for PA applications, focusing on real-time support on the machine by web services. In the present study, standards of the OGC were used to transfer and analyze the data. For example, a weed application was mentioned in Kraatz *et al.* (2015) that is supported by the work of sensors, sending local and regional data to an "online precision farming system" which analyzed the data and refreshes the machine-located application map. Mortensen *et al.* (2019) presented a toolbox detecting regions of interest in unmanned aerial vehicles (UAV)-images by a MATLAB-toolbox. He mentioned limitations of developed image-processing by the license of the software. UAVs have become popular in agriculture, as they make fast data sampling possible. They are relative cheap platforms with a wide spectrum of possible sensors and a high resolution. Their relevance has increased in agriculture for several years. Since the platforms have reached a high level of quality, research on the sensors and their data processing has to follow (Tsouros, 2019). As PA needs a close to sense operation, scanning flights with immediate processing is an interesting possibility for field operations. Regarding this need, Geipel *et al.* (2015) used a standardized infrastructure to stream data from a UAV to a server for further analysis. Therefore, the location of the infrastructure's components does not matter, as long as interfaces are defined, and a way of transfer is given. Nowadays the location independence computing is closely linked to cloud computing.

OGC-services are prepared for the implementation into cloud computing architecture. Evangelidis *et al.* (2014) described a framework for geospatial cloud computing as a multi-tier client-server architecture, using service interfaces of the OGC. He further emphasized the benefit of the integration of computer systems into incompatible platforms by standardized interfaces. Such incompatible platforms also exist in PA. Standardized interfaces could help to overcome limitations. Exemplarily Lee & Kim (2018) realized an implementation of an OGC WPS for a geo-based image analysis in a cloud platform. He used the Platform-as-a-Service (PaaS)-technology as a scalable backend. He wanted to make the underling procedures, in the current case image processing, as modular and expandable as possible. While PaaS offers a prepared platform for the developer, it reduces efforts for setting up the infrastructure. No operating system or software has to configure on a server. The developer gets access to a working environment. A higher degree of provisioning is Function-as-a-Service (FaaS) (Van Eyk *et al.*, 2017), where the runtime environment of a function is also prepared next to the platform and could be requested by web-technologies. The benefit of FaaS is the noneffort (Van Eyk *et al.*, 2017). Sugob (2019) described FaaS as the environment on which engineers can deploy their functions or snippets of business logic.

In the current article, we explored the possibilities and capabilities of a standardized service, offering functionalities to PA-applications. We built this service, which is located directly above raw data, and supports software of the end-user via specific processing. We explored and investigated the optimal infrastructure for the realization of PA-software. Our task is to get familiar with working methods and material, like the OGC WPS and UML modelling, to analyze the activities of two PA-use-cases by UML and proof the proposed concept by realizing one use-case in real field conditions.

Material and methods

Standardization

In the present research, we focused on the potential of standards and cloud technologies for PA operations. This intention was achieved by offering service-based functions for data processing. As PA deals with location specific information, the standards of the OGC were used. Regarding the needs of PA and taking the demand of a SOA and standardization into account, attention in the development of an optimized infrastructure has to focus on the realization and publication of functions by standardized services. The OGC WPS fits best with these demands. Therefore, we analyzed its functionalities to offer descriptions and processes by a web interface.

These web services can perform anything from simple requests to complex quantitative models or analysis by artificial intelligence. The complexity is outsourced to a server offering the service. In the realized examples, a client with little computing power can calculate a vegetation index and an image analysis.

Theory from information science

In information science, the DIKW-model, representing the connectivity of data–information–knowledge–wisdom, is a theoretical framework. It describes the process of appreciation of data, while ordering terms by quality and quantity. Lokers *et al.* (2016) interpreted those processes for the agricultural domain, treating data as raw material, which is unprocessed input from sensors. Through interpretation (*i.e.*, adding meaning) the level of information is reached. This transformation could happen with models and data analysis. The level of knowledge is reached by using applications, which add options or scenarios. This level might be defined as a Decision Support System (DSS). Above all, this is the level of knowledge, reflecting interests and references. Fig. 1 expands the transformation of Lokers *et al.* (2016), who worked on the use of big data in agro-environmental science, by equivalent objects in PA. While data in PA is sampled by sensors or is delivered from databases, the step to knowledge (*e.g.* FMIS) and wisdom (field operation) crosses the information layer. Transmitted to the language of software-engineers, we expect a backend layer in preparing the data, becoming the coded functions. Currently these codes are mixed with the software of the knowledge level. A clear partition requires a separation of information and knowledge. This layer of knowledge can be described as an interface to human and machinery users. It is the visible screen design of a FMIS-client, as well as the interface to the task controller of the machine.

The separation into layers brings the benefit of a clear division of tasks. Thereby flexibility of the software increases, as layers can be treated as exchangeable elements and the development could be focused on its specific challenges. This is important, when a special expertise, as needed, for example, to analyze or model complex systems of plants in the field, is transferred to software code.

Modelling PA-operations and their proof of concept

Models are general and flexible tools, which are extensible and could be combined with others. Software developers use them to support the optimization of processes. The common construction by model-driven architecture is done by using the Unified Modelling Language (UML) to visualize and analyze context. The UML offers several modelling methods to prepare creation of software solutions after analyzing real-world processes (The Object Management Group, 2017). In particular for complex systems, dealing with several users and dependencies, the UML is a tool of choice. Papajorgji *et al.* (2009) showed the successful transfer of modelling methods from software development for developing agriculture. Nash *et al.* (2009) presented a soil testing case for a PA use.

The concept of the web-based data processing was created by a use-case based approach. Inspired by the methology of Nash *et al.* (2009) and Papajorgji *et al.* (2009) typical workflows were modeled. We developed models to fill the identified gap exemplary for two use-cases. The first complement is a scientific experiment in weed science, and it calculates a vegetation index. Second is an approach for the rescue of wildlife in pre-harvesting.

Scenario of use-case I

The modeled use-case of a weed application is based on the idea of Geipel *et al.* (2015), to connect an UAV with a field computer by a real-time communication. The developed web service enables direct analysis. In combination, this builds up the backend for field operations base on the input of an UAV above the working field. The use-case is the generation of an application map for weed management done by a tractor, which sends its position with a shift depending on speed and calculation time to the field computer. The computer requests the service to calculate a plant index by available images from the UAV. Depending on the returning value, the machine regulates its work. The calculation done by a field computer is an ambitious task. It is well suited for the export of logic to a service as a function of the service (FaaS).

Scenario of use-case II

By the scenario of a wildlife detection and deer alert system, we wish to demonstrate how the public domain could benefit from offering FaaS to farmers. Instead of functionality, the public sector already offers open data

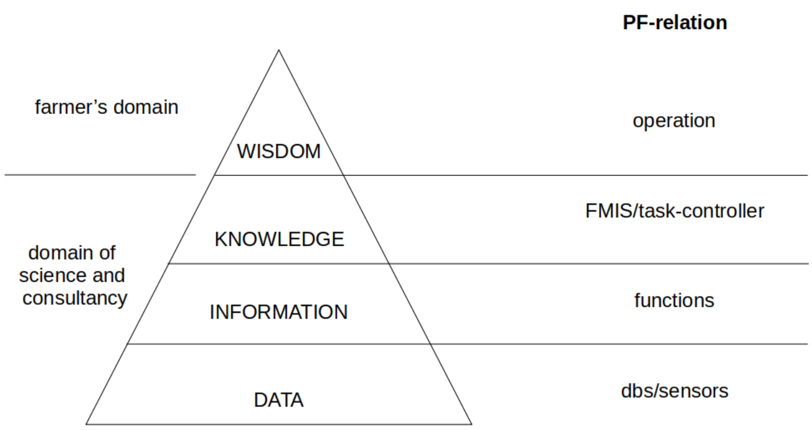

Figure1. DIKW-model adapted from Lokers *et al.* (2016) transferred to precision farming

(*e.g.* the European INSPIRE directive), and benefits are well discussed (*e.g.* Kucera & Chlapek, 2014).

Accidents involving animals during field operations are negative for the farmer as well for the public, which is interested in protection of nature. A wildlife-detection-service, financed or offered from the publicly domain, is here modelled in UML. It presents the cooperation between public authority and agriculture. The service includes the function for analysing UAV-images.

Using a model driven approach, we analyzed the needs of architecture and proofed functionality of the developed solution. The development is created towards the demands of a comprehensive, but extensible, model of activities. Thereby it focuses on business logic instead of individual details of a high-specialized sensor system. We explain which activities are expected from different chair holders, as data supplier (*e.g.* farmer), consultant/scientist/public domain, machine/farmer in an UML-activity-diagram.

We constituted a model procedure to proof the approach. From image analysis of a drone-based sampling, a vegetation index is calculated and forwarded to an application map.

Data sampling

The data sampling took place at the Heidfeld Hof research station (48.71° N, 9.18° E) of the University of Hohenheim (Stuttgart, Germany) in 2019. The average annual temperature and precipitation were 8.5 °C and 685 mm. The soil was a Luvisol derived from loess.

In 27 plots of 3 m × 23 m, winter wheat was seeded in October 2018. The row distance was 0.15 m. Eight different field treatments were performed, along with an untreated control (Table 1). In the treated plots, different weed control strategies were applied, like herbicide application, harrowing, hoeing and their combinations.

The UAV-based field surveillance was performed using a quad-copter type Phantom-4-Advanced V2.0 (Da-Jiang Innovations Science and Technology Co., Ltd, Shenzhen, China) in March 2019. The copter integrated a gimbal aligned RGB-camera with a focal length of 8.8 mm, an image resolution of 5472 × 3078 pixels and a mechanical shutter. The flight altitude was set to 36 m above ground level, resulting in a ground sampling distance of 0.99 cm.

Table 1. Treatments applied to the plots.

No. variant	Treatment
1	untreated (control)
2	herbicide
3	harrow (2x)
4	hoe (3 km/h) (2x)
5	hoe (8 km/h) (2x)
6	hoe (6 km/h) (2x)
7	harrow (1x) + hoe (1x)
8	hoe + herbicide (early)
9	hoe + herbicide (late)

Infrastructure

Geipel (2015) developed the idea of real-time information transport. The UAV is "chatting" during flight with the ground computer by predefined IT-interfaces. Data are available in real-time for further processing. We extended the described data sampling and add analysis.

The image interpretation took place in the 52° North (52°North Spatial Information Research GmbH, https://52north.org/) WPS web client (Fig. 2). The web client is a user interface, offering a map viewer and an WPS-interface. Through this interface, functions could integrate and execute from the working environment. Therefore, the service was registered to the client by naming the URL and process.

In the background an OGC WPS from a web service publishing GeoServer (Open Source Geospatial Foundation, 2020; http://geoserver.org/) was processing requests. The GeoServer is a web-based Geographic Information System (GIS), which can publish spatial data services. It ran on a Tomcat 8 (The Apache Tomcat Foundation, 2020; http://tomcat.apache.org/) server-environment. This enabled the server to act as a web server to communicate with clients, such as external software websites or, more specifically, the previously named WPS client.

The service extended the software for doing analysis for precision farming tasks. The client was not previously optimized for the operation which was added to the service by specifying the server. By choosing the specific processing from a menu, a short description appears to introduce the user to the possibilities. This additional process enriched the client-software.

Image interpretation

Image interpretation was done by the excess green minus excess red index (ExGR). ExGR has been proven for similar operations (Mink *et al.*, 2018; Gerhards *et al.*, 2020). One of the index's main advantages was its use of "simple" color channels, as they are offered by standard RGB-cameras, which made investment costs much lower, along with the need for specialized solutions. ExGR provides quite robust results in various scenarios, by just using a zero (0) threshold. The ExGR is using the bands of an RGB-camera to calculate an index, which gives information about the vitally level of a plant and about the coverage of the ground.

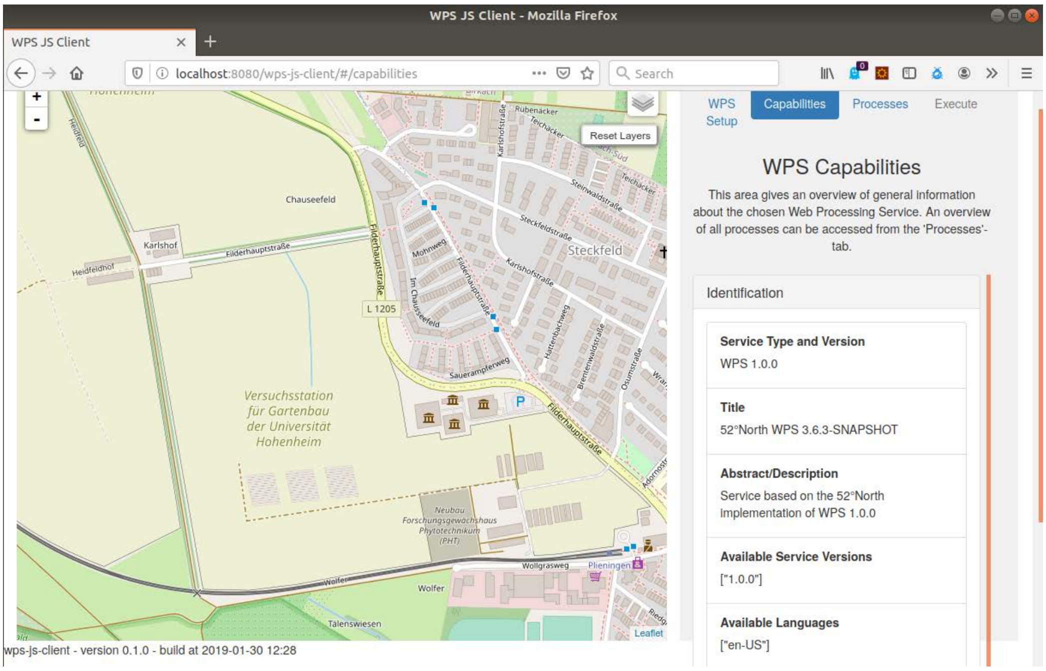

Figure 2. 52° North web client integrating the ExGR-web-service. The OpenStreetMap Viewer gives an overview complemented by an overlaying layer of the field trial's boundaries. The capabilities describe the loaded processing service.

The index uses following notation with two color indices:

$$ExGR = ExG–ExR \quad (1)$$

where ExG (Woebbecke*et al.*, 1995) is

$$ExG = 2*g–r–b \quad (2)$$

and ExR (Meyer *et al.*, 2004) is

$$ExR = 1.4*r–g \quad (3)$$

Based on (2) and (3), (1) can be represented as:

$$ExGR = (2*g–r–b)–(1.4*r–g) \quad (4)$$

where, for each pixel, g represents the value of the normalized green pixel, r represents the value of the normalized red pixel and b the value of the normalized blue pixel.

The result of the ExGR is positive for vegetation and respectively for vital vegetation. Non-vegetation objects like soil mainly cause values below zero. Our attention is on the transferability of the method. Since this calculation provided good results in the past (Mink *et al.*, 2018), our main focus is to examine how easily can it be transferred and what is its potential in a FaaS-oriented intergration.

Image processing and integration into infrastructure

Processing of the ExGR-index per plot was realized by an R-script, running on the server, which also hosted the frontend-tools. R is popular in science as a language for statistics (Team R Core, 2021). With the use of the 52 North WPS4R-extension of the OGC WPS, it was possible to offer standardized WPS-services, including the logic of R-scripts (Hinz, 2013). This was done by adding predefined comments to the script and registering it at the WPS4R-server. The preparation of R-scripts consisted of the following elements in the header:

 # wps.des: ExGR, title = Excess Green Red,
 # abstract = Calculates ExGR for raster image in chosen spatial plots.;
 # wps.in: urldir, string, abstract = "URL or directory of the data.", value ="https://www.mydatacloud.com/data";
 # wps.in: plotno, double, value=448;

In this way, the service got its name and title. The abstract was used with the client to describe in more detail what the service was about. By following the "wps.in" parameter the input to the service was defined. Beside the names of parameters that could be used in the ongoing script, there was the option of additional information and default values. In the script the lines of R-modelling of the ExGR follow. In these lines, data from the path-variable 'urldir' were imported, pointed to the directory of the image and a spatial data file, describing the polygon of each plot. A plot was chosen by the input of 'plotno' and the ExGR was calculated. The result was written directly to a file. Alternatively, it could also be written to a screen output with a line for the output:

 # wps.out: result, string, title= values for application of selected plot;

Results

Use-case I: Weed application

Activity-diagram

To analyze the use-case and carve out the role of FaaS, Fig. 3a presents an activity diagram of the process. It divides the activities into three instances: data supplier, which might be the same person as the farmer, machine, possibly operated by the farmer, and FaaS, which might be a consultant, a scientist or from the public domain. The central aspect is the division into the close-to-famer-operation (data-supplier and machine) and the external-operation. Second, it includes the process of data to information and knowledge. A higher knowledge about measurements in field operations is needed for an environmental situation, which is contributed by experts.

Architecture

Fig. 4 shows the basic elements of the architecture combing the field operation with a cloud service. We chose an architecture, which setup was open for a cloud environment. This environment, called the backend, was doing data processing and could be separated into a data- and a function-backend. It also offered a function for image interpretation as a service through a standardized interface. The service was used by network-access, sending requests including the specific parameters of the actual situation of operation. It was suitable for the objective to integrate innovations and knowledge into the environment with an importable function. The function was offered as a service; therefore, we used the term of FaaS.

Processing

The used R-script delivered serious results, which were identical to a local analysis, as the working script in the background was identical, as well. As expected with the different treatments, the results of each plot differed. Table 2 and Fig. 5 present the results of the ExGR. As the images are from March, plants were in the beginning of their growth period. The crop should not have achieved the majority of its canopy closure and plant coverage was expected to be below the visible soil. Negative values, as expected, represent the dominating non-vegetation areas. Even so, there are noticeable differences between the untreated (highest mean) and treated plots (*e.g.* weeder treated plots).

Use-case II: Wildlife detection

The use-case, presented in Fig. 3b, assumes that the farmer registers the field of operation at the beginning of the working day. The supporting consultant, public authority or

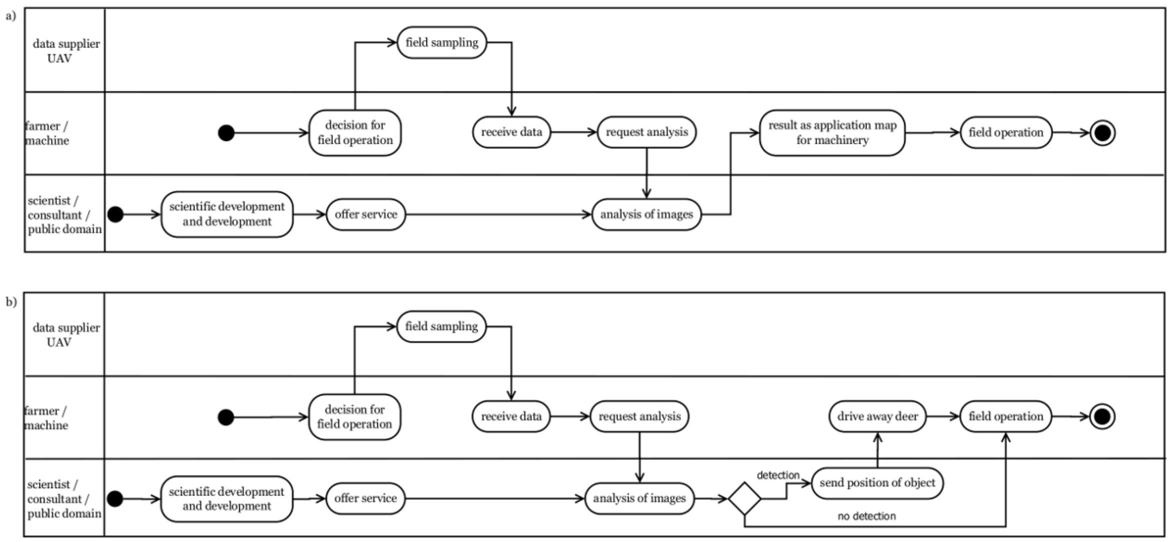

Figure 3. Activity-diagrams modelling the generation of an application map (a) and a deer alert system (b)

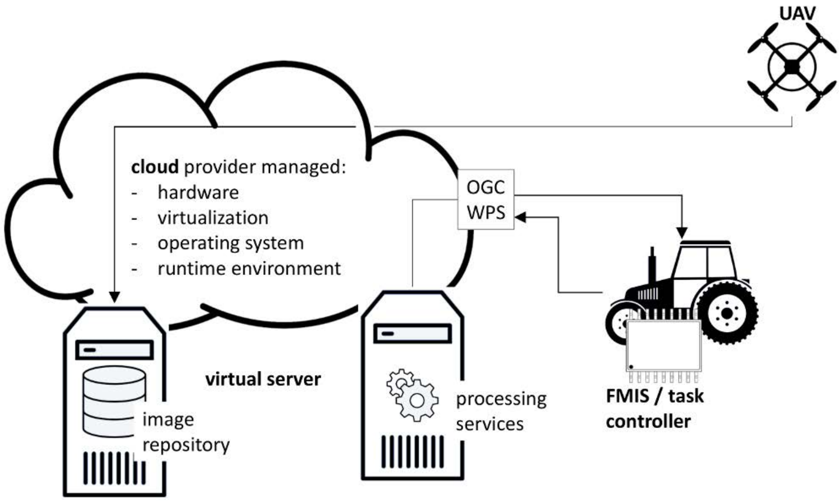

Figure 4. Schematic view of the IT-infrastructure for a drone-supported precision agriculture (PA) application. OGC: Open Geospatial Consortium. WPS: Web Processing Service.

Table 2. Results of ExGR (mean of pixels per plot) by different weed managements including their mean and standard deviation per variant

No. variant	Treatment	ExGR	Mean	Standard deviation
1	Control (untreated)	-0.183	-0.193	0.011
		-0.190		
		-0.208		
2	Herbicide	-0.183	-0.224	0.034
		-0.223		
		-0.266		
3	Weeder (2x)	-0.215	-0.242	0.024
		-0.236		
		-0.274		
4	Harrow, slow (3 km/h) (2x)	-0.199	-0.218	0.014
		-0.224		
		-0.233		
5	Harrow, fast (8 km/h) (2x)	-0.211	-0.222	0.015
		-0.213		
		-0.243		
6	Harrow, medium (6 km/h) (2x)	-0.211	-0.231	0.019
		-0.224		
		-0.257		
7	Weeder (1x) + Harrow (1x)	-0.257	-0.237	0.014
		-0.226		
		-0.228		
8	Harrow, slow (3 km/h) + Herbicide (early)	-0.191	-0.203	0.011
		-0.200		
		-0.218		
9	Harrow, slow (3 km/h) + Herbicide (late)	-0.192	-0.218	0.023
		-0.214		
		-0.248		

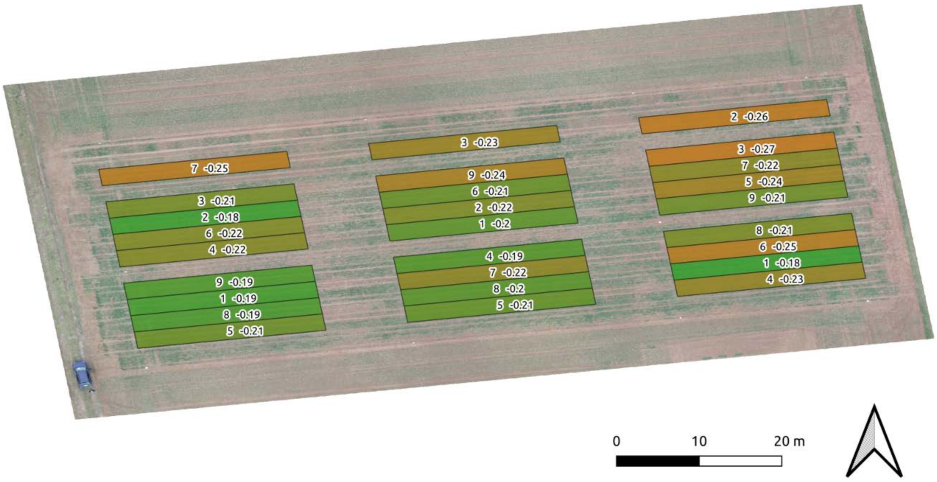

Figure 5. Map of results of different treatments and ExGR (excess green minus excess red index).

scientific institution requests data from an UAV, which are sampled on demand. With the streamed field data, a function checks for wildlife within the field. In case of a risk, it informs the machine before reaching the field-location.

The role of the FaaS is to offer a function, which is sensible enough, and its underlying infrastructure is strong enough to analyze the images with a minimum of delay. For the public authority, additional investments are needed, but there is repayment in the way of nature protection and support of local farming.

General note

Both use-cases assume a shared and common interest in the optimized operation. The results are transferable, as we noticed more or less the same components and an identical infrastructure. Even when the operation differs, the differences in the solution consists only of the algorithms for processing.

The acting group consists of a data supplier, which might be included in the person of the farmer or farming company, the machinery, which is the vendor, on the one hand, and the farmer, on the other, and consultants or public authorities, which have to improve operations by their specialized knowledge. The group of users are identical, as is the same for several parts of the modelled activities and used technologies. For example, both activities work with an UAV equipped by an RGB-camera.

Discussion

The present research works out the benefit of a decentral logic behind machinery and user interface of the FMIS. The runtime environment is server-based, flexible concerning the location of the components and open for cloud-based infrastructure. By the modelled use-cases, we present the fitness of components and their benefit for the involved parties. While Martínez *et al.* (2016) and Kaivosoja *et al.* (2013) implemented different data sources into a PA infrastructure, we added the component of processing and reached a higher level of data handling. Thereby we followed the idea of Nash *et al.* (2009) and used the WPS-standard of the OGC and implemented it as an FaaS. The benefits of an WPS as an FaaS are drawn up: we developed an infrastructure, that allows the addition of new functionalities to a user-software only by implementation of the OGC-WPS-interface. Thus, collaboration between different parties could be promoted and specific expertise could be used. Additionally, externalization of calculations onto server infrastructures is a benefit for challenging, computationally intensive operations, especially if use differs over time.

These benefits by external services are well known in other domains. We show how to integrate these techniques into agricultural field operations. Collaborative approaches between public, private and business are possible, supported by WPS- and FaaS-technologies. Software development benefits from parted functionalities. While features of software increase, time of development decreases. The process of development and updating could happen while running businesses in the background, unrecognized by the user.

The whole software is scalable by its depth of integration and calculation power. The possible increase of calculation power, in particular, supports complex algorithms. Regarding the needs of calculations in agriculture, which are used periodically and not for a whole year, FaaS could shrink available computing power and increase it on demand during field operations.

Compared to commonly known processes of data analysis, an important advantage is the processing option. While data transfer might be a disadvantage, depending on the local infrastructure. On the one hand, new mobile data transmission approaches and mobile networks are being established, and, on the other hand, technical solutions like "Moving Code" (Müller *et al.*, 2010) offer solutions. In this specific solution, code could be imported on the side of the client instead of transferring huge, sensed datasets to the server. As it uses the OGC-WPS-interface a client can use both solutions in a hybrid way. For the farmer, it is not relevant how the backend works, as long as the software functions properly, which is achieved through coordinated, standardized interfaces.

The WPS, which has been used here, belongs to a broad toolbox of standards for spatial data handling. It has been proven as a powerful instrument in manifold domains. For the transfer to PA the final result from all data processing has to reach the machinery. This was proven by Kaivosoja *et al.* (2013), Kraatz *et al.* (2015) and others in transferring operation-relevant information onto the task controller. For further developments the APIs of the OGC might be of interest, which follow actual technical developments. The present case of this work might benefit from the OGC API–processes specification (Open Geospatial Consortium, 2021).

The analyzed technologies enable an advantageous accounting model for the provider of FaaS in agriculture with the possibility of usage-oriented billing. As a result of upcoming trends in agriculture, like autonomous machines, sensor networks and sensor platforms (*e.g.*, low altitude platforms), meaning derived from actual software-architectural models increases. These models are reasonable for making the step from agro-industry to data-driven production. Thereby, decision making about the characteristics at a specific working location could be taken into account. Algorithms have to fit to local circumstances to improve PA (Dyer, 2016). The presented technologies are appropriate tools to bring this benefit to the farmer.

The same technologies and same users are involved in both use-cases. The integration of FaaS into a farming spatial data infrastructure does not need new or different UAVs and sensors. Present tools can be reutilized and extended by incorporating necessary functions for each instance of task-external knowledge. The option of using a common R-script, which is a popular method to analyze data in science, is easy to implement into PA data infrastructure. Manufacturers of a FMIS benefit by extending their offered solutions in integrating only one interface. The manufacturer gets a unique selling point through its permanent growing functions. This business model could be transferred from other markets like IT (*e.g.* open APIs of google) or the car industry (*e.g.* Mercedes-Benz/developers), where the leading brands cooperate with (other) software developers to improve their product, which do not has to be an IT-product. The idea of open interfaces supports manufacturer's efforts to open their software environments for data exchange, like Wolfert *et al.* (2017) described.

The data exchange makes a sensitive data handling necessary. For example, the General Data Protection Regulation (GDPR) of the European Union has high demands on the provider of services regarding the handling of personalized data. Its relevance increases when the systems get more open and exchange data. In our examples, accuracy per centimeter can be assigned to a landowner, a manager or a worker. This should be taken into consideration and specific protection measures and generalization techniques need to be established. One technological approach is the industrial data space. It creates spaces of different states of openness in the frame of produced datasets. The owner of a dataset keeps control of it, even if it is used by other parties. The effort of managing access rights might be too large for a single farmer, and he might then choose the simplest and safest for him way of blocking any kind of data exchange. Yet this could have negative results - both for him and for society. Here a further idea from other domains might enrich agriculture's IT-infrastructure: data cooperatives, groups with the same interests face this challenge through joint decision or the delegation to experts (Blasimme *et al.*, 2018).

The presented infrastructure offers advantages for PA with its flexibility and scalability. Every group of users gains benefit from it. First of all, the farmer gets access to a highly individualized software with adapted functions. These functions could be offered by the manufacturer itself but could also be offered by others, such as science or public authorities. An FMIS, extended by the OGC-WPS-interface, becomes a tool for the interaction of different parties. The product's quality increases, which is positive for the manufacturer. Public authorities could offer their own logic, taking regional circumstances into account, and scientists would have a way to transfer their results immediately into practice.

After the evolution towards SOAs in agriculture, FaaS-technology with collaborative partnerships might be the next step. Combined with a modular FMIS and further importing of values from external sources, or from machinery in real-time, a new way of data handling could be realized. The final improvement to field- and situational-characteristics might be the import of functions to enrich the agricultural value chain. Concrete examples of approaches could be image analysis, as depicted, but could also be error corrections of datasets, as these are calculation-intensive and appear only periodically.

The presented expansion is a main element of an agricultural IT-infrastructure, which would allow for analysis of bigger and more complex data sources. Thereby its relevance grows with the growing importance of IoT. Even mobile solutions are supported or at first enabled by the outsourcing of computational processes.

As a next step, a professional FMIS should open up for the OGC WPS interface to analyze options of integration into the user interface. In particular, description of offered functions is relevant for developer and user, depending on depth of integration. Here use of metadata, as it is usual for data analysis, is a challenge that has to be solved. Parallel to the integration of open interfaces into FMIS, products might create an ecosystem for entrepreneurship to create new solutions and improvements of PA.

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Chapter 6

Increasing safety of farm machines in public traffic information systems by using data from precision farming

Jackenkroll, M.; Gerhards, R.: Increasing safety of farm machines in public traffic information systems by using data from precision farming. (Submitted to Agronomy)

An SDI consists by definition of four components (cf. Section 2):

- Spatial data
- Spatial data services
- Metadata
- Network environment

In the domain of geoinformatics these are solved by technological standards and methods. In the previous sections, they were transferred to PA field operations. Thereby a concept of an improved spatial data infrastructure for PA was created. It has been shown how standards from other domains inspire the potential of agriculture. Motivated by the successful example, a standard from another domain is linked to agriculture's IT-infrastructure. The domain of traffic information works with the exchange standard DATEX II, established by the European commission and widely spread for mobility data descriptions in the member states.
The point of contact between both domains' information is the geo-position. On the agricultural machine it is handled by the ISOBUS and could be provided by most modern tractors. By mapping it to transport information, the machine is an identifiable object in the traffic. This might be relevant for safety reasons. The presented solution is based on the risk of accidents between fast moving vehicles and slower acting agricultural machinery on the roads. Accidents are preventable by publishing location and behavior of the machines in an anonymous way to central traffic information platforms. As the exchange is done in a standardized way, it could be read by electronic driving assistants to warn drivers.

Using the spatial information, handled on the machine for PA-purposes and its further use, above the originally idea of the manufacturer, an additional benefit could be created. It is obvious, that openness for data handling of foreign domains is finally a profit for PA and its users.

Article

Increasing safety of farm machines in public traffic information systems by using data from precision farming

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Abstract: Agricultural machines are optimized for field operations. On public roads, they impede faster moving cars and trucks increasing the risk for accidents. Nowadays, tractors, cars and trucks are often connected to networks and send or receive datastreams. These data are transfered by domain-specific standards into or from information systems. In the present paper, we investigated a concept to link and map data from the standardized agricultural machine bus ISO 11783 included in a farm management information system (FMIS) to the European traffic information standard DATEX II. For connecting these two domain-specific standards, we developed a d2d-switch to inform car- and truck drivers (or autonomous vehicles) about a slower moving agricultural machine in the near distance. This specific case proofs the potential for domain overriding data exchange. Simultanously it is an example of the benefits generated by creating the link between data infrastructures through the concept of the international data space. That will increase the safety of agricultural traffic on public raods mainly for long-distance transport of liquid organic manure, pesticide applications and harvest operations.

Keywords: agricultural machine, standardization, ISO 11783, DATEX II, traffic management system

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1. Introduction

Agricultural vehicles are built for effective field work in difficult terrain. They are designed for their operations in the field, irrelevant if they work on muddy soil, carrying heavy loads or on steep hillsides. But when the machine is on its way to or from the field, it is on public roads and it might impede other vehicles. Due to contracting and increasing exchange of goods between farms, such as pesticide applications, export of liquid organic manure and harvesting, long-distance traffic of agricultural machines on public roads becomes necessary. Thereby, the machine differs by speed and dimension from other road users. Further they stress the conditions of the surface by dirt from the field.

Brannolte [1] analysed the risk and slow-down on public roads by agricultural vehicles 30 years ago. With an average speed of 25 km h-1, tractors moved much slower on public roads than cars and trucks. Slow-moving vehicles cause a higher risk of accidents and hinder the free flow of traffic. They also enter and leave public roads at unexpected positions. In a South Korean research paper presented by Kim *et al.* [2], almost 2/3 of accidents with tractors happened offsite from the fields on public roads. They were mainly caused by collisions from behind. Even though countries might differ concerning farm structures and traffic of agricultural machines on public roads, the study of Kim *et al.* [2] highlights the risk associated with tractors on public roads. The results of this study were verified by investigations of the General Association of the German insurance industry (UDV) in 2011. According to that study, 86.5% of all traffic accidents with tractor happened during turning into farm roads, entering or crossing public roads or by traveling in the same direction. Bende and Kühn [3] also stated that accidents with farm maschines on public roads were often serious and above average deadly. Pinzke and Lundqvist [4] and Brannolte [1] also mentioned the risk of accidents of tractors in public traffic systems with other road users. Brannolte [1] pointed out the need for optimized infrastructure to reduce the risk of accidents with tractors and Pinzke and Lundqvist [4] suggested supporting traffic partners with automatic information systems. Those information systems should identify potential critical situations on public roads. Bende and Kühn [3] proposed a technical assistent for the agricultural machine warning the machine-driver by on-board sensors. To inform the car's driver or internal car logic the European Telecommunications Standards Intitute (ETSI) lists a standard of a direct communication between the vehicles [5]. Therefore, they propose to use a machine-to-machine (m2m) communication, creating an interface on the precision agriculture machinery. Further, the CLAAS KGaA mbH developed a large vehicle alert system in a cooperation with BMW AG [6]. Awarded by honors, like the silver medal of the leading trade fair AGRITECHNICA, its relevance and acceptance in agricultural has been seen.

Nevertheless, an m2m communication between car and agricultural machinery is not transfered to the market yet. The role of solutions will increase by autonomous vehicles. While decentralized communication technologies might dominate in future, an interim solution for the communication between modern vehicles and non-m2m-ready-vehicles is needed (cf. Auerswald *et al.* [7]) and might further be important as a second layer to ensure savety. To exchange data Buchholz *et al.* [8] mentioned two relevant standards for the data exchange in situations and events. Besides decentralized environmental notification messages (DENM), which is a standard of the ETSI for the m2m-exchange, he listed the DATEX II, which is described in more details below and offers the possibility of exchange by a simple network access, as it is usual for mobile phones or a large number of nowadays vehicles. Nevertheless, a hybrid solution for the exchange of information is nesecceary to overcome lacks like short reaction times, the risk of malfunctions etc. For future autonomous driving it is a central component of the data exchange between vehicles as well as intelligent transport systems stations [8]. The technologies, which are used on modern tractors have all prerequisites by being equipped with computers, being web enabled and knowing about their position. Additional apps and software solutions offer services on the real-time information of the machine's working processesby reading its internal data bus, e.g. exatrek (https://exatrek.de).

In transportation science, ideas concerning the information of road users were developed (e.g. Stübing *et al.* [9]). The practical traffic management is mainly done by traffic signs - partly as electronic displays operated by local or regional control centers. Navigation assistants have an increasing impact on the travel behaviour of drivers. These tools are implemented directly in the cars or are running on the mobile devices of the driver. They are integrated into information infrastructures, informing about the traveling behaviour of others and the actual road situation from online sources. At the same time, there are data languages to describe and exchange traffic and travel information. Through use of software-based tools, the modeling of an accident-prevention traffic information chain from incident to the receipt of on-board information is possible (Figure 1).

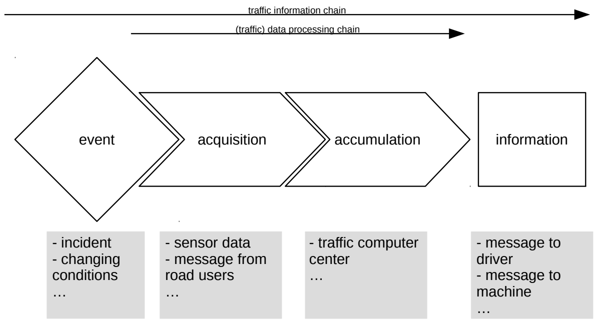

Figure 1. An information chain to prevent accidents in traffic.

The traffic information chain in Figure 1 includes several sources. There are systems of the public authorities and the police who share their knowledge concerning the situation on the road ("event"). Nowadays, the influence of app-driven solutions by communities have increased. They can be separated into active ones, where users enter information by interaction with the app, and ones working in the background, exchanging the users travelling behaviour and interpreting the situation ("acquisition"). In the latter case, they work with a base of mass data collected by a huge number of users. Their relevance increases with more and more "intelligent" vehicles, which are equipped with sensors and which are linked to each other and to central server units or, in the common way, by traffic computer centers. Data is accumulated by them ("accumulation") and could be interpreted and used according to the position or situation of a specific vehicle. This might be a message to the driver or situation specific behaviour of the vehicle itself ("information").

This study describes the potential for precision farming technologies combined with current transportation information system to increase safety on public roads. Accepted concepts, entering future automotive products, exspecially for automatic driving, are introduced. Their potential role as an interface between the two worlds of transportation information systems and agriculture should be analysed to create the linkage and to reduce accidents on public roads.

2. Materials and Methods

2.1. Data standards for traffic information

Traffic and mobility have decisive importance for the economy. The exchange of traffic information is a tool to increase the efficiency of traffic. For intelligent transport systems Auerswald *et al.* [10] identified three communicaton technologies to exchange information between vehicles and infrastructure: Besides device-to-device technologies, like 802.11p and C-V2X, which are no global de-facto standards yet, the communication by cellular networks provides a promising approach that implies less barriers for nowadays traffic communication. The cellular networks already connect vehicles and infrastructure. Several nations have installed traffic information centers. The interaction between these institutions takes place by IT-interfaces. Nationwide standards enable cooperation. The European Union unified the exchange of information with its own machine and human readable standard called DATEX.

2.2. European standard DATEX II

Meanwhile the second version of DATEX (DATEX II) has been in use since 2003. Its focus is on interoperability, and it has been published in the third subversion. DATEX II is based on XML schemes modelling needs. These are subsets so-called profiles. The profiles represent the topics, which have to be described. For instance, there are profiles for roadworks, traffic signs, parking sites etc.

DATEX II is in use by several national iniatives all over Europe and is pushed to be the standard for traffic information in the European Union. All national platforms support the objective of a wide use by offering out-of-license restrictions [11]. The main objective of DATEX-II-use was to implement intelligent traffic [11]. He lists three needs from the information technology (IT) view, which are the linking of business-processes, the IT-systems themselves and the machines and on-building algorithms. The implementation itself respects the use of standards like UML, XML, http(s), SOAP etc. One further standard is OpenLR, which is used for localizing, which then supports the transmission of data in order for it to be collected on different geographic basemaps. Datasets benefit from this property in mapping processes with other datasets. Profiles in DATEX II could be customized to specific needs. The format supports the flexibility to expand the standardized core.

2.3. Example for data-accumulation: German data-broker "Mobilitätsdatenmarktplatz"

The standardization of traffic information was a first step of the European Union to optimize the data exchange. In a next step, central data-brokers are set up to create an access point for each member nation. They are called National Access Points (NAP). Therefore, Germany established the "Mobilitätsdatenmarktplatz" (MDM) as a national access point [12]. It is a marketplace between providers and consumers of traffic data. In technical terms, it is a broker offering metadata and linking users. Its technical language is, if possible, DATEX II. Users are called to use official DATEX II-profiles, also there are several application-oriented once and "containers" for data in any manner [11]. The more standardized the data description is, the more its further use is realizable, and its attraction for further utilization by world-wide active companies increases. In its further development the MDM will be connected to the "Datenraum Mobilität" (DRM) – a data exchange platform, designed to the framework of the international data spaces (IDS). The IDS offers a reference architecture with a focus on the trustful inter-domain exchange of data. Described in the Otto *et al.* [13] IDS-connectors secure the exchange between a data provider and a data consumer. Before the data exchange get realized, the parties get informed about the available data by metadata, an explaining vocabulary and a broker service. The use of the offered data is supported by tools from an app-store and controlled by a clearing service.

2.4. Information for the car driver

Nowadays, drivers inform themselves with apps and vehicle-integrated navigation systems for trip recommendations. From the basis of maps and incoming data streams about traffic jams, construction sites, accidents and weather conditions the routing is at a high level in respect to exactness and warning against risky situations. Further benefits might be the saving of time [14] and of energy [15].

In transportation science, there are ideas concerning information about slow-moving vehicles. For instance, there is a patent [16] about bringing warning messages (with the example of bikes) into the on-board electronic notifications for faster moving cars. With the realization of autonomous driving the relevance of infrastructure-to-vehicle- (I2V) and vehicle-to-vehicle- (V2V) communication increases. For construction sites information exchange was realized by local ad-hoc networks (Die Autobahn GmbH des Bundes 2021) and cellular networks [17]. Figure 2 describes their implementation for an agricultural machine entering the road, following the high-level architecture of Buchholz *et al.* [8]. In the ad-hoc networks the machinery is sending a message directly to the approximate car. The information is forwarded to other vehicles, as long as they are equipped with the technology. Parallel cellular networks are used to broadcast the information, informing also cars, which are not equipped or to far away from the sender. The used architecture model is described in more details in Buchholz *et al.* [8].

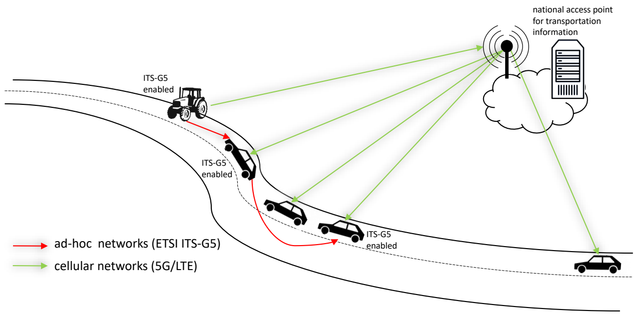

Figure 2. Traffic communication regarding the high-level architecture of Buchholz *et al.* [8].

Currently, car manufacturers develop solutions for both options of communication. Public institution in Europe and the United States of America, which are important markets for further technological developments, stopped their support towards the use of ad-hoc networks in transportation [18]. DATEX II and national data-broker are the European way to optimize the traffic. The consortium of several countries (an area of more than 380 million inhabitants [19] makes it attractive for further processing. Several manufacturers of navigation solutions accepted the standard and request information from the European NAPs. As the published information is machine-readable, it could be directly integrated into on-board-electronic navigation devices, webclients or apps. The additional information and based upon services are unique selling points and highly relevant for manufacturers. Therefore, the provider of navigation systems include data from the MDM as well as further official sources and backflow from their users.

2.5. Information from agricultural machine

2.5.1. ISO-11783

Modern machines in agriculture use a standardized bus for information, called the International Standardization Organization Binary Unit System (ISOBUS). ISOBUS is a standardized way for hardware (e.g. plugs), for providing information, such as the usability of displays. It is defined in ISO 11783 and was established on the tractor, implement and FMIS. Besides the plugs, it defines the method and format of the data-transfer and the user-interfaces; it also forms the interface to the vehicle bus standard CAN (Controller Area Network). Its relevance has increased by the development of precision farming (PF) and the importance of transparency concerning agricultural production. In 2013, already 50% of the tractor vehicles were equipped with ISOBUS [20]. For high-grade machinery, in particular, it is a basic feature.

Addressing the whole infrastructure of agriculture machinery and processes, ISOBUS is a key element for bringing the internet of things to the fields. This means that more or less every measurable element, which is controllable or approachable in an electronic way, could be connected to an IT-network and might reach the world wide web. It includes the localization of objects. Since nowadays agriculture is based on the location of action, named PF, ISOBUS supports location-based data by the TC-GEO-functionality, which was developed by the Agricultural Industry Electronics Foundation (AEF). It works on ISO-XML as an exchange format and supports, for example, application maps.

2.5.2. Potential of standardization for farm machinery

The ISO 11783 stands for high compatibility between machines and attachments. Simultaneously, it is a door-opener for IT-oriented companies into the world of farm machinery. Through the standardized data exchange in agriculture, small companies could take root. IT-services for machines are possible and offer additional options to the owner. More and more solutions from new players on the market aim on a farmwise information handling. The value of the information might be higher, however, if it got used in overall domains.

2.6. Modelling the switch between different domains

The present paper follows the idea of combining the data of the two previously mentioned domains. Therefore, it was analyzed from business processes to software development using the open-source software DIA. The process was modeled on the business processing modelling notation (BPMN), and the software development was done in the unified modeling language (UML) notation.

- BPMN: Its maxim is to clarify the process for every user. Especially in trans-sectoral processes, it is an essential tool to inform the stakeholders.
- UML-notation: The UML works with different diagrams to illuminate manifold views on a process from a technology point. The starting point is normally a class-diagram.

2.7. Technical framework of the domain-to-domain-switch

The transfer of information from a domain-specific system to a foreign one needs an understanding of the content from both sides. Thus, a domain-to-domain-switch (d2d-switch) needs expert knowledge for each domain. The transfer could happen in a so-called data-broker. A main disadvantage is the high level of customization, which means that every new, individual source or output must be generated individually. Standardization is a key element to prevent this, and more or less every domain has its own data-standards, which cover a wide range of the domain-specific data streams.

In the case of analysed domains, the mentioned standards ISO11783 and DATEX II are good examples. By developing these interfaces, an applicable solution could be created. From the business point of view, this means a large number of potential customers.

3. Results

3.1. Combining different domain specific standards

As described by Freudentein [11], the linking of IT-systems and the business-processes represented by them must be an objective for intelligent solutions exemplary in traffic information. Traffic information and agricultural information are handled each in powerful data ecosystems. Both are boosters of their domains and will change the way they work in the next years. The main idea of this paper is to combine these two worlds to obtain a benefit. As an interface a server will be used to transfer the information from the ISOBUS, with the underlying FMIS respectively, to the traffic specific standard DATEX-II and be published on the MDM plattform. From there on the information could be forwarded to navigation services and broadcasted to the driver. Thereby a BPMN is a good base for a further discussion.

3.2. Business process model of the domain-to-domain-switch

With the challenge of bringing two different domains together on the level of IT-services, a clear picture is necessary. Stakeholders from both sides have to understand the language and thinking of a foreign domain; they need to be convinced and to bewilling to open their interfaces.

A business process model represents the whole procedure. Through its standardized notation and its simple structure, it is readable for everyone. The visualization makes for a fast overview without going too much into details. In particular, technical details should be avoided. A comprehensive overview about BPMN is given by Von Rosing *et al.* [21].

Figure 3 presents the BPMN the process of data exchange and the generating of information.

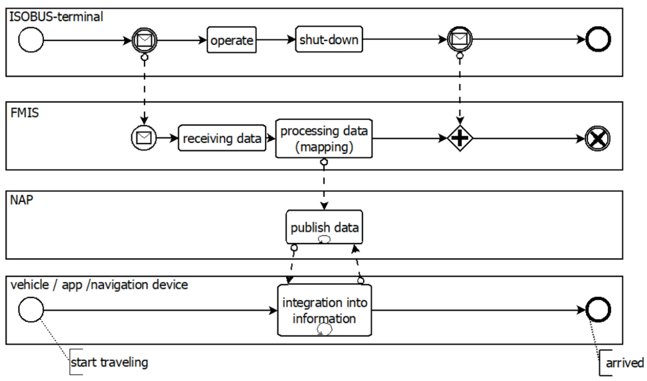

Figure 3. Business process connecting an agricultural machine controller with the traveling information.

A new process on the machine initiates the start-up of the ISOBUS-terminal. It sends data to an FMIS until shut-down. It processes the data. The central process in this use-case is the mapping of the incoming datastream to a traffic-information-conformation format, which is published on a platform and is thereby forwarding the data to clients like a vehicles, apps or a navigation devices. The information is matched with the route of travel and the driver is informed about situations of interest ahead.

3.3. *UML-class diagram of the d2d-switch*

In order to bring the idea closer to a software-based realisation, a more technical view is needed. UML has been proven in this context. It is used to analyse a process by its objectives.

The working process was analysed with an UML-class-model. A class diagram is optimized to give an overview of the solutions structure with its essential objects ("classes") and their relationships.

As the data source ("ISOBUS-terminal") and the receivers ("navigation device", " app", "vehicle") are fixed and described by the BPMN, the main focus of the UML is on the interfaces and their linked objects (Figure 4).

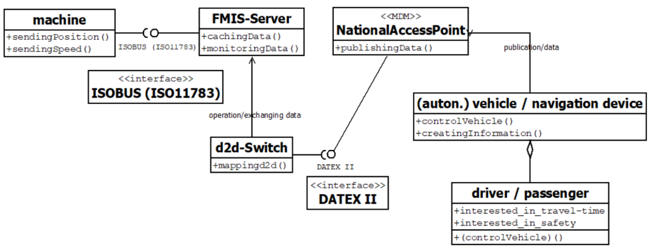

Figure 4. UML-class-diagram connecting an agricultural machine controller with the traveling information by a d2d-switch.

The standardized interfaces of both domains are qualified by their wide range. As ISOBUS does not deliever a human readable data stream, it is connected to an information system, usually a FMIS. For switching the data to the traffic information in DATEX II the d2d-switch is needed. Its realisation is the core component of this development.

3.4. *Using information for a risk-threshold*

Position and speed of the agricultural machine, correlated with the speed of the faster vehicle, result in a threshold about the risk of an accident. As well, the delay of all involved components has to taken into account:

$$th = \begin{cases} 1 \text{ if } f(d, v, t_{delay}) \geq 0, \\ 0 \text{ if } f(d, v, t_{delay}) < 0, \end{cases} \quad (1)$$

with
th: threshold for warning or reaction
d: distance between car or truck and agricultural machine
v: speed of car or truck
t_{delay}: time of delay of involved technological components

A descision support system could use the threshold to warn about a situation with a high risk as soon as it shifts to "1".

3.5. *Privacy and data security*

Location data of single machines and workers needs a high level of privacy. Otherwise, there is no chance to establish the service. Increasing privacy, as required for the data exchange of traffic information in the European Union by the delegated regulation 886/2013, will happen by anonymisation. This is done by the data collecting server, where several FMIS are registered. While the incoming data are machine specific, the output is homogenized. Only the relevant information position, speed and class of vehicle are forwarded, but it cannot allocate to the source any longer. From this point onwards, a specific machine is only a slow-driving vehicle. In near future the next generation of the German NAP is expected to expand the functionality concerning data security by following the idea of international data spaces, called mobility data space. It enables the direct and protected data exchange between partners.

4. Discussion

Food production in agriculture requires to use of modern information- and automation technologies. Those technologies are often more profitable if farms cooperate and use the technologies on several farms or if farmers outsource operations to contractors. Legislative regulations force farmers to exchange goods between farms. That includes for instance organic manure, which needs to be exported to other farms to prevent accumulation of nutrientsi in the soils. All these constraints will increase agricultural traffic on public roads and cause risks of accidents. Therefore, investigations are needed to make agricultural transportation on public roads safer.

The developed concept clarifies the benefit of combining datastreams from different domains. The idea, representing one pillar of the onward developing internet of things, focuses on agriculture machinery. The potential is given by the technology, used for PF. By expanding its functionality offsite from the fields, a further benefit of the machine-IT could be created. This is especially likely if the used standards enable a realistic scenario for the implementation, as they offer the potential of transferability. ISOBUS opens the idea to a wide datasource and DATEX II to a wide use. By combining the mentioned standards, benefit to machine drivers and every other road user are generated. The transfer of the information into a treshhold based risk analysis supports a safer transport. The use of a communication through cellular networks allows a simple to integrate technology. Nevertheless, insufficient network coverage or long delays of the signals are reasons for direct communications inbetween the vehicles. The solutions by mobile networks might still be useful as a second layer in a savety-related application. Furthermore, proactive planning routing solutions might integrate the additional source a long time before car and agricultural machinery could contact each other. The use of standards allows for simple access to the data of each domain. Close to science or interested developers are enabled to build services on existing technologies. Agriculture and the market of machinery can avail themselves of this opportunity.

The presented idea is only one possibility. The exchange with other domains might be a benefit on its own. IT-techologies, as long as they are not reduced to proprietary software solutions, are a main development sector for manufacturers. Concurrent associations or the public sector can support this by offering central data-hubs and the standardization of interfaces. Thereby security concerns of the data provider have to be considered.

Privacy might be a reason for reluctance in being a provider of a datastream for the developed application. The anonymisation of the input was described above. A second step to secured data handlingis the concept of the industrial data space, but this was not taken into account in this development. It is a protected, virtual room belonging to the data-owner. Only the owner is in the postion to give access or to limit it. Here again, usibility is given by standardized interfaces and the option of simple access [22]. The industrial data space was transferred to the data-based operations in agriculture. Actual research also transmits the idea to mobility data and will enter the further development of the MDM. Particularly farmers might not be interested in further efforts for data administration. A model of cooperation, which is well known for farmers, (c.f. agricultural cooperatives) might help. In data cooperatives, (cf. Blasimme *et al.* [23]) a merger of producers of data determine collaboration about the data use. Single members could transfer their vote to others.

5. Conclusions

The modeled use-case shows a successful and useful combination of different standards from different domains. As the internet of things (IoT) is called the next step of technology development, and it might be reasonable for cross-domain engineering. There are already approaches to combine different data models e.g. the open-source-tools of FIWARE. Present standardized interfaces arealways a main requirement. Further, the unhindered access to the data is necessary. In the specific example, agriculture data infrastructures are used to make traffic information systems safer by already installed technologies on the majority of farm machines. Solutions by additional on-board-sensors are not needed. Even for modern vehicles with V2V- and V2X-equipment, the solution by cellular network standards is a useful supplement needed for savety reasons as a second way of communication.

The PF-equipment has a great potential for further d2d-services and the continued building of IoT. By the use of recognized platforms and the mapping between accepted standards, an inter-manufacturer-coordination is unnecessary.

Further research might invest in more benefits for both sides in the combination of agriculture and traffic information. Here we analysed the forwarding of data about position and speed, but we do not examine other obvious applications. For example, the road conditions after field work could be mapped into the same DATEX-II-profile by the attribute “NonWeatherRelatedRoadConditions.” The delegated regulation 886/2013 of the European commission motivated producer of security-related data to publish them for the purpose of a save travel.

Also, the exchange can be improved. While we described a one-way information stream from the tractor to cars and trucks, a fast-moving vehicle as a transmitter might warn the agricultural machine driver before he does risky manoeuvres.

In the near future autonomous driving will get higher relevance in mobility. Therefore, detailed information about the situation for traffic routes are needed, and approaches like the one presented here might be one contribution.

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Abbreviations

The following abbreviations are used in this manuscript:

AEF	Agricultural industry electronics foundation
BPMN	business processing modelling notation
CAN	Controller area network
d2d	domain-to-domain
DENM	Decentralized environmental notification messages
DRM	Datenraum Mobilität
ETSI	European Telecommunications Standards Intitute
FMIS	Farm management information system
I2V	Infrastructure-to-vehicle
IDS	International data spaces
IoT	Internet of Things
ISOBUS	International Standardization Organization Binary Unit System
IT	Information technology
MDM	Mobilitätsdatenmarktplatz
NAP	National access point
PF	Precision farming
UML	Unified modeling language
V2V	Vehicle-to-vehicle

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Chapter 7

General Discussion

This thesis follows the idea of improving the handling of spatial data in PA through underlying data infrastructure. As Karpinski (2014) identified technologies as the driver for agriculture, spatial technologies, namely geoinformatics, are examined in this thesis as a potential for spatial oriented agriculture, namely PA. The implementation includes the concept of an SDI.

The demands on the SDI for PA operations were defined by the objectives of this thesis: (i) to increase the usability of PA-tools in order to open the technology for a wider group of users, (ii) to include external data and services seamlessly through standardized interfaces to PA-applications, (iii) to support exchange with other domains concerning data and technology, (iv) to create a modern PA-software architecture, which allows new players and known brands to support processes in PA and to develop new business segments, (v) to use IT as a driver for agriculture and to contribute to the digitalization of agriculture.

The following discussion connects the objectives in relation to the conducted research. Additionally, a general view of an SDI for PA is given, including issues that have to be clarified for further developments with regards to the spatial data handling.

7.1 Potential of an SDI for PA

The development of an SDI follows the definition by components, which are the data, the services, the metadata, and the connecting environment. The components are relevant to make the data transfer between different participants of the PA-process as easy as possible.

Starting with the first component, the data, the whole communication of the PA value chain, is relevant. Every quantitative captured state is a datapoint that could be processed into information, knowledge or wisdom (Lokers et al. 2016). The value of data is increased by the potential of further handling by IT. Data is generated by sensors. In particular, sensors are one main requirement for PA (Stafford 2000) and are indispensable from PA nowadays. They are mounted on diverse platforms of diverse participants. To get the added value, their measurements must be further processed and combined. To avoid laborious, case-related solutions, a data infrastructure offers the appropriate environment. Nash et al. (2009) described this solution for PA as SOA based. The services are another key component. They represent the interfaces and thereby the means of in- and output.

The objective of high usability for applied software is in striving for seamless communication. This means that the communication occurs without any additional human activities like changing the medium or the format or any other manual intervention. For this need, standardized interfaces have been proven effective and flexible for different circumstances. Combined with the SOA as a fixed criterion for all SDI's in this research, the seamless exchange through networks could be ensured. Thereby the location becomes irrelevant. Weaknesses of single parts in the infrastructure are balanced by others, for example in the case of calculation power.
The mentioned components of the SDI work in coordination, creating the basis for automated processes and supporting users during PA-processes. For the human user and also for machining (e.g. artificial intelligence, web crawler etc.), interaction, data and services have to be described. The SDI considers, therefore, metadata, descriptions of the data and services. Korduan (2004) identified, that there are no PA-oriented profiles for metadata, but there are approaches for extensions of prevalent profiles.
The focus of an SDI is on the sharing, use and access to spatial data by different parties. Fountas et al. (2015) identified a clustering of functions in agricultural software. To overcome this barrier, a re-design of software architectures is needed. An increasing number of cooperative software products appeared on the market, in order to work with marketplaces (e.g. DKE-Data GmbH & Co. KG 2020). Once the framework of an SDI is included, a strengthening of PA is possible. PA benefits by extending emergent or existing data infrastructures to an SDI, as spatial information has a high relevance. The proposed interfaces allow the integration and exchange (even multidisciplinary) of different services, extending the functionalities of the software and increasing the usability of PA. Through standardized interfaces, data and services are modifiable. Regarding changing circumstances in field management (for reasons like climate change, invasive species, new plant diseases etc.) the technology has the needed flexibility to support the farmer or farm-manager.
As shown in this work, information and knowledge could be imported from farm-related or external sources by the SDI's interfaces. Relevance increases from the changing production methods as there is a division of work, and the tractor is driven by an employed driver or, in the near future, autonomously as a robot.
Sørensen et al. (2010) described the required flexibility of farming software, because of the manifold types of farms. By following the SDI-approach, it is possible to add processes to a software without any changes at the frontend or client. The modular integration of functionalities supports more specific business models. The software could be individualized to the needs of a farmer, and the manufacturer could charge performance related fees. Simultaneously, classic brands of agriculture could outsource specific parts of their software or plan in partnerships to increase product experience. All mentioned user groups benefit by the increased usebility of the PA-tools using the analysed components of an SDI-architecture.

7.2 Technologies for spatial data management

Nash et al. (2009) recommended a SOA for PA. Meanwhile this paradigm for software solutions was accepted in the development of agricultural IT. Well-known brands offer online services and use modular software, which is supported by SOA. Solutions like nevonex (Robert Bosch GmbH 2020) are based on the idea as well as the presented use cases. This research integrated services, which are exchangeable. The approach

is supported by the use of standardized interfaces, which are realized only partially in the market. Companies might protect their own developments, but they simultaneously reduce the usability and functionality of their products. This understanding might be the reason that they allow more and more general data exchange. Initially this data exchange was organized in collaboration with other partners. Furthermore, the import of external spatial data sources like Web Map Service (WMS) and Web Feature Service (WFS), which was analyzed in this thesis is realized in some solutions.
Another trend, that enters agriculture software from IT are platform solutions. In particular, data are outsourced from the farm IT-infrastructure to servers of machine- or consultancy-brands. By web interfaces or apps, farmer can access structured data views and interact. Examples are agrirouter (DKE-Data GmbH & Co. KG 2020) , 365FarmNet (365FarmNet GmbH 2020) or exatrek (EXA Computing GmbH 2020). The usability has significantly improved. Such platforms run in server or cloud environments. Cloud-computing fits well to the business structures of farming. Managed like other companies, the data is kept central. A large amount of data is produced during all business processes. The extensible design of cloud-servers is predestined to manage these. Additionally, the access takes place on the web. The farm manager can get an overview about the processes independent from the client and the position. Also, in addition to the exchange with other manufacturers, consultancies, customers or authorities, a cloud could offer admissions. On the side of the farm, no efforts are needed to install and configure the IT-infrastructure. For the integration into farm management, Kaloxylos et al. (2012) emphasized the meaning of standardized interfaces for complementing tools in his vision of clouds in agriculture.
Meanwhile the cloud is more than a storage- and marketplace. There are working services to increase the value of incoming data. For PA, being close to the field operation, the variable computing power of cloud servers is relevant as every working process varies greatly throughout the seasons. Similar to the data-management, open standardized interfaces are valuable. Expert knowledge is becoming available without technological barriers.
Based on the relevance of cloud computing in future PA, this study analyzed the option to operate an OGC standardized service in a cloud as a Function-as-a-Service (FaaS).The OGC standards offer the Web Processing Service (WPS) to realize processings with a spatial background that undertake the role as a FaaS. Analyses, not only of spatial data, are possible, offered by microservices and the benefits of a cloud, as the regulation of computing power, fit to the needs of PA.
A further trend influencing PA is the IoT. As sensors are one component of PA, objects in PA are used to be known, data-sending 'things'. The vision of IoT links these objects to networks. Coming from stationary sensor networks, Tzounis et al. (2017) expected a development to micro-precision in greenhouses, but also in farmland. Kaloxylos et al. (2012) stressed the various objects, which are to deliver data from a farm, and pointed to a middleware in the data infrastructure to handle it. This middleware as a context broker has to be developed for every delivering sensor system to create a homogenous output. If the infrastructure works on standards, as defined for an SDI, further data processing is to facilitate. The development of a sensor middleware connecting a UAV and other sensors to a structured data handling of a sensor network by the OGC Sensor Web Enablement (SWE) is an example in this work. It proved the options of the standardized SDI for the IoT, in particular by the processing of data streams in real-time. The standards of the OGC will further developed to provide support for the

evaluation of the IoT (Simonis 2019).
Closely connected to IoT, as it generates a huge amount of data, is the trend of 'big data'. The automated analysis, potentially by artificial intelligence (AI), enables new views to established processes. 'Big data' is particularly interesting when datasets of more than one farm are connected. This connection needs the exchange an SDI is designed for. Besides the regional factor the datasets have to take evaluations into account. This shows the importance of the spatial component of the datasets. Finally, the optimized data handling of an SDI supports the concept of digital twins. The terminology means that a real time object, for example a field, is mapped into the world of data. A digital description is generated from all accessible data. It requires more sensors and will offer a "close to" alert-message reaction by the farmer (Paraforos et al. 2019). To benefit this way from further data, the infrastructure has be initially created. The SDI offers a concept for the assembling of data and framework for a further use, which is till now a problem, as they are dispersed (Fountas et al. 2015).
All presented components of an SDI were realized through open licensed software-products. Next to low cost (for the beginning to minimize the economic barrier), it is the community-concept, which makes it attractive for the users. Farmers, which are in general no IT-experts, might hesitate, but as with proprietary solutions, service providers would set up complete environments. A main advantage is the open code, which allow insights and creates trust. As the data are of a high value for the farmer, this factor is highly relevant.

7.3 Standardization for PA data handling

7.3.1 Relevance of standardization

The European Commission (2016) identified the agriculture sector as highly prioritized for standardization in information and communication technologies. Especially smart farming is mentioned as benefiting from a standardization in the services of the data. In relation to PA, the most relevant standards are the ISO 11783 / ISOBUS, involved the ISO-XML, and conditionally agroXML. Each has its specific focus and strength. For PA, Nash et al. (2009) noticed the importance of the exchange between partners of spatial data. The standards of the OGC best fit the needs and are optimized for the concept of an SDI. Additionally, they offer a wide range of functionalities, whose focus is congruent with requirements from PA, like data exchange between different partners, data description, raster and vector data handling, sensor data handling, data processing etc. A domain working group at the OGC (Open Geospatial Consortium Inc. 2020) focuses on the handling of agricultural data. Its mission is to develop existing standards towards the needs of agriculture or to even develop new standards with the object of interoperability. Besides others, they aim for the harmonization between the OGC and ISOBUS as well as between OGC and agroXML. The presented components of an SDI illustrate the gains by opening the farmer's applications for appropriate data and services. The integration of additional information as shown, could be pushed by more available data services. For example, the INSPIRE-directive binds European governmental agencies to publish their spatial data in an SDI. Therefore, the standards of the OGC are used. Korduan (2013) explained benefits and barriers. The final realization had to be implemented in 2020. Based on the resulting potential of accessible data, a valuable addition for PA is possible, if the corresponding interfaces are realized and the data's semantics

are clarified (cf. 7.3.2).
The interest of the public society might also motivate authorities to fund the infrastructure, like above mentioned in the case of the INSPIRE-initiative. Digital solutions might help to guide agriculture in a socially requested way. Clapp and Ruder (2020) mentioned the social interest, which has to overcome the limitations that impede the modernization to an IT-driven agriculture. An exemplary use case was presented in this work by the protection of ground water through an SDI-connected task controller. Nevertheless, the quality of the available data is relevant. As PA works within sub-meter, the precision of the data has to be on the same level. In particular, public data are often not precise enough and further investiture is needed if applications should generate from them.
For the choice of the correct external dataset, information about them is needed. Metadata are a central component of an SDI. The exchange could be handled by the OGC Catalog Service for the Web (CSW). Besides this exchange standard, there are standards for the description (Korduan 2004). Simultaneously, standardized interfaces could be applied for communication from the farm to external partners, like governmental agencies (to simplify documentation obligation), consultancies (to support the optimization of processes) or science.
The use of the standards from the geospatial domain is meaningful. As spatial science is interdisciplinary oriented and the OGC standards are used in many different domains, their use promotes the exchange with other domains, which is a benefit for both sides. The combination of input results in added value. The described exchange with traffic information systems is as an example.
The open standards provide professionals from other domains the option to integrate their knowledge. The SDI is the breeding ground for an IT-ecosystem for new products and solutions.

7.3.2 Selection of standards in the SDI

Beside the standards of web-technologies and general IT, the research focuses on the spatial oriented standards, which are developed and published by the OGC. Section 2 gives an overview about the PA-relevant standards. These are the OGC WMS for georeferenced images, the OGC WFS for georeferenced vector data, the OGC Web Coverage Service (WCS) for georeferenced raster datasets, the OGC CSW for metadata, the OGC WPS for processing and the, in Section 4 used, standards of the OGC SWE for sensor integration.
The OGC offers in addition to these service-oriented standards, data-oriented standards like the OGC Geography Markup Language (GML) or the OGC GeoPackage. Both are appropriate formats instead of the still used shape-file-format. They are open and more flexible concerning complex data. In Section 3 GML is applied for mapping the application task. It fulfills all needs to push information from a PA-operation forward to the ISOBUS. Further individual application schemas are possible. The GML gets a subject specific structure. Basic research for a PA-application schema has been done in the GeoWebAgri II-project (GeoWebAgri 2020). The relevance of an individual application schema for PA is reasonable, as the data from standardized interfaces is not self-explanatory. Through an arranged GML data schema, the semantic is clarified and transferable. A common schema for PA would also help to facilitate the merge of disassembled datasets, as they are an existing barrier in PA (Fountas et al. 2015).

7.3.3 Standardized spatial data handling use cases

In three different experiments, standardized, OGC-conforming services were tested. Each experiment focused on another use case and standard.
The first, described in Section 3, used a data import for a variable rate control application in weed management. A WMS added georeferenced raster images. This support came to the driver as additional information on the screen of the application monitor. Additional vector data were transferred to the machine, bringing areas of a special, ecological management interest to the task controller. The data of the requested WFS influenced the field operation automatically. Usability, on the one hand, and nature protection, on the other hand, got support by the OGC services. The research further showed the location-independence of the data processing, as the task controller was located in Finland and the supporting server was in from Germany. Using the demonstrated technologies external sources could support PA with specific data. As an example, the European INSPIRE-directive (European Commission 2020) with the objective to make existing spatial datasets at public authorities available (Nash et al. 2009) and uses the same OGC standards as analyzed.
In a second use case (Section 4), an OGC SWE was setup. This environment is optimized for the integration of sensor data. As there are manifold types of sensors, the standard allows a flexible mapping of them. Data from a UAV, a tractor and a local sensor were collected for further processing. The variety of sensors is relevant for PA, as it is based on the comprehensive sensing. Further the on-the-fly transfer of data from the UAV, also implemented by IT-standards, and their immediate management in the OGC SWE shows an optimal data treatment for PA.
Section 5 analyzed the processing by OGC standards, as Daróczi et al. (2013) emphasized the meaning of data processing in PA. The WPS describes a service that offers a processing for spatial and non-spatial data by networks. It was used for the interpretation of UAV-images. A simple vegetation index was calculated as an example, but simultaneous demonstrat, that much more complex processing is possible, as the service could be placed in a cloud environment. WPS-interfaces allow an integration of functionalities from external partners.
All experiments presented the benefits of the use of well-documented interfaces and a SOA. Still there are barriers to overcome. All solutions need stable networks. As they partly work on the machine during field operations, the SOA might reach a weak point because of less mobile network coverage or bandwidth. There are local solutions to partially overcome such problems. In connection with the OGC WPS, a stationary solution is described. Müller et al. (2010) developed a 'moving code' for how the SDI works even under conditions like defective network-availability. In these cases, the runtime of the standardized service is integrated onto the client hardware. The server sends the code to perform the processing instead of receiving the data. Solutions like this might also be relevant if PA deals with large data sets, for example aerial images. On the one hand, the network is less used; on the other hand, the client has to do the calculation. The developer of the specific SDI has to choose the optimum for his needs. A positive effect of an architecture on standardized interfaces is that the software of the user does not need any changes.
The fact that agriculture is data driven is also realized outside the domain. Politics push the expansion of the mobile phone networks. The next generation of this technology is often mentioned together with PA use cases. Connection related problems should be solved in the near future.

7.3.4 Social and political aspects of the data management

Especially for small farms, which are until now hardly represented in PA (Balafoutis et al. 2017), the proposed implementation of tools and architecture is interesting. Until now, mainly bigger farms, able to invest and take a risk, profit from the application of PA technologies (Balafoutis et al. 2017). They improve their business and have another competitive advantage compared to the small- and medium-size farms (Rotz et al. 2019). Low barriers for these smaller agricultural businesses might be open source software products to keep them competitive on the market with the industrial farms, to manage duties of documentation for the authorities or to handle the wishes of customers for the highest level of transparency for their products. In order to involve small or medium farms by adding the benefits to them, the idea of open source for farming software, has to be expanded to the data and, as presented, to suitably designed services. Besides community-based approaches, the public authorities might fill this position to support farming, which is in the interest of the society.

Moreover, the ownership of data has to be clarified. Williamson et al. (2003) mentioned these policies as an additional aspect of an SDI. These policies form an outer frame to organize the data-exchange. One approach that has been mentioned is an agricultural data space. The concept is based on the industrial data space and is used in the industry and the service sector. It belongs to the strategy of digitalization of global players, e.g. thyssenkrupp AG (Achatz 2017). A data space ensures connection between partners for an exchange of data and offers the tools to control and secure it. Of the highest priority is the sovereignty of the data, which means, when transferred to agriculture, that the farmer or farm-manager as producer and owner can control their usage. For this realization standardization will be relevant.

PA necessitates a legal framework for data, and respectively farmer have to be sensitized to the value of their data. Kritikos (2017) mentions the problem and Clapp and Ruder (2020) describes the potential for an unwanted economic use of farmers' data by companies for their development of products. Further scenarios are imaginable in connection with the finance- or insurance-industries. The policies, belonging to an SDI are necessary. Nevertheless, an open standardized SDI might offer the needed transparency, and would thereby offer trust for the user, since the interfaces are documented and accessible. Rotz et al. (2019), in evaluating the politics of digital agricultural technologies, points concerning the sovereignty of data to technologies and data systems that are open and cooperative. Furthermore, Rotz et al. (2019) mentioned the meaning of the fit to local circumstances and suggests public funding.

Even so, tools and rules would be defined by an SDI and would increase trust in the use of PA, the additional work for the organization of the data might be a barrier for the farmer. In addition to the work, uncertainty might a barrier to control the data exchange, which would mean an inhibitory effect on PA. Therefore an organizational concept was suggested in the studies of this thesis: data cooperatives, similar as it is known by the farmers for the marketing of products, which might follow common interests and define common rules for the use of their data. Inside a cooperative, knowledge about the handling of data could be exchanged or could be delegated to an expert.

7.4 Challenges in the PA-SDI

The research shows SDI's potential through several use cases. SDI's utility is located between data-creation and its use and visualization directly on the machinery or for the human user. The communication should happen by standardized interfaces. As an example, a standardized in- and output was realized. Within the SDI the interaction between components and partners is ensured. As a barrier proprietary architectures exist in the market, which do not allow access to their raw measurements. The target must be to open and combine them. Corporations between the manufacturers on platforms for customers are first approaches. Against the background of a clear personal ownership of the data (Clapp and Ruder 2020), further steps are possible. For the realization, the concept of an SDI combined with the idea of agricultural data space is obvious. Fountas et al. (2015) noticed that PA activities should planned, carried out and monitored at sub-field scale by taking as many datasets about the environment into account as possible, and that the development of software has to include more complex information. He further mentioned the increased demands on the exchange in PA-software.

Another lack nowadays for PA is their priory use in big farms, caused by the high initial costs for the PA-equipment. Through their investment, these farms can produce more efficiently. The competition for medium and small farms becomes tougher. As agriculture is much more than the production of food and raw material – it is an ecological system and a formative factor of our cultural landscape – this development might be a critical issue. Finger et al. (2019) identified small and cheap IT-solutions as an option to make PA attractive for smaller farms. SOA makes a modular use possible. Supplementation by the community-idea, for example an IT-environment of an agricultural cooperative, and assistance from the public authority might be helpful for datasets or services. Against the background of the positive ecological effects, the Kritikos (2017) recommends tools and incentives for this group of farms.

In spite of all these possibilities for IT in PA, the human factor is still relevant. IoT and 'big data' will create new decision processes by AI. An appropriate SDI might support these concepts for best available and described data. Nevertheless, the AI could not replace the monitoring, decision making and control of the farmer or farm manager. AI works on data and might make better suggestions than a human. But the technology is overstrained when new concepts have to be introduced.

7.5 Perspective of SDIs in PA

PA has the potential for economic benefits as well as positive social, in particular ecological, effects (Stafford 2000). Against the background, that the use of PA underperforms, Clapp and Ruder (2020) mentioned the possibility of legal provisions or the reduction of barriers by improving the technology. The research on the SDI pursues the second possibility. By an improved spatial data handling via an SDI the added value of PA could be increased. Balafoutis et al. (2017) mentioned the protection of the environment as a welcomed side effect. Such effects are possible through an SDI, by allowing the exchange to outer data-sources and -receivers, as Section 3 presents. Also, as a further social reason, the use case of the minimization of incidents-risks, as analyzed in Section 5, are enabled by the opportunities given by an SDI. Thereby the spatial data handling of PA should be influenced by more parties than just the manufacturers. Organized farmers and public authorities, as well as science, have to shape the processes, too.

Examples like emerging platforms and marketplaces as years earlier the developer of agroXML (Doluschitz et al. 2005), have realized the importance of the data exchange between different parties. The SDI allows the extension of these collaborative approaches to the PA-operations. By the relocation of agricultural software into the world wide web, mobile interfaces on smartphones and further technological developments, PA gets an upswing. Aulbur et al. (2019) identifies, among others, the inclusion of sensors, automatization and digitalization. How such an integration could be realized is presented as an example in Section 4, where different sensors are connected to a managed database by standardized interfaces. In the future, the linkage of data will be extended, and onward processes will be developed. Another promising concept is the concept of digital twins, which might be supported by an optimized data handling of an SDI.
The digitalization of agriculture proceeds. PA was one of the first areas where computers influenced field applications. IoT and automatization will further develop the systems and tools. The underlying infrastructure has to accompany this process. The components of an SDI and the included standardized interfaces have the potential to meet these challenges.

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Chapter 8

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