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Applications of open geospatial web services in precision agriculture: a review

Edward Nash · Peter Korduan · Ralf Bill

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Abstract Precision agriculture requires the collection, storage, sharing and analysis of large quantities of spatially referenced data. For this data to be effectively used, it must be transferred between different hardware, software and organisations. These data flows currently present a hurdle to uptake of precision agriculture as the multitude of data models, formats, interfaces and reference systems in use result in incompatibilities. This paper presents work on applying standards from the Open Geospatial Consortium and related initiatives to automate agricultural data processing. The selected use-cases demonstrate how such standards may be used to improve the inter-operability of data and software in precision agriculture.

Keywords Automation · Data management · Standardisation · Web services · Workflows

Introduction

The analysis of geospatially referenced data plays a central role in effective precision agriculture (PA). The complexity of the software and the high costs in terms of both money and time required for the management of this data are found to be barriers to the more widespread adoption of PA (e.g. Fountas et al. 2005; McBratney et al. 2005; Jarfe and Werner 2000), and farmers are likely to have limited skills and/or interest in this area (Kitchen et al. 2005). In particular, the lack of inter-operability between different software

E. Nash (✉) · P. Korduan · R. Bill
Chair of Geodesy and Geoinformatics, Institute for Management of Rural Areas,
Faculty of Agricultural and Environmental Sciences, Rostock University,
Justus-von-Liebig-Weg 6, 18059 Rostock, Germany
e-mail: edward.nash@uni-rostock.de

P. Korduan
e-mail: peter.korduan@uni-rostock.de

R. Bill
e-mail: ralf.bill@uni-rostock.de

is identified as a problem (Kitchen et al. 2005). Exactly this problem of inter-operability of spatially referenced data between software and systems has been the focus of much work in the geographic information (GI) community over the last 15 years, with many standardisation initiatives now coming to fruition based around the work of the Open Geospatial Consortium, Inc. (OGC) and ISO/TC211 Geographic Information/Geomatics. The general-purpose 'OpenGIS®' standards produced by this process may be applied in a range of fields, including PA. Of particular interest for PA are the standards for transfer of geospatial data using web-services, which allow information to be exchanged on-demand between distributed systems.

In this paper, we summarise current standardisation initiatives in PA and the concept of web-services before describing some of the OpenGIS standards with most relevance to PA. We then describe some use-cases for these standards to demonstrate how they may be applied to automating data flows for common procedures in precision agriculture.

Inter-operability and standardisation in precision agriculture

Standardisation initiatives in the agricultural domain such as LBS (DIN 9684, 'Landwirtschaftliches Bus-System'/'Agricultural Bus System') and its successor ISOBUS (ISO11783, 'Tractors and machinery for agriculture and forestry—serial control and communications data network') projects have largely focussed on hardware compatibility. Although ISOBUS includes aspects (ISO/FDIS 11783-10, 'Task controller and management information system data interchange') concerning communication at the software level between farm management information systems (FMIS) and board computers, there currently exist no international standards for communication on a software level between different FMIS. The problem of incompatibility between systems has consistently been cited as a hindrance to adoption of PA (e.g. Pedersen et al. 2004; Reichardt and Juergens 2006). Particularly where specialist models and software are to be used, it is likely that these will run as stand-alone software requiring data inputs which are already available in digital form in a FMIS or as data gathered by sensors mounted on-board a tractor or connected implements and communicating using a bus platform (e.g. according to the ISOBUS standard) or wireless in-field sensors. The use of a standard data format for these data, enabling a direct file-based transfer, would significantly improve this aspect of data flow. Initiatives currently exist for defining such formats (e.g. agroXML Kunisch et al. 2009; AgXML 2009), with extensions including complex precision-farming data (Steinberger et al. 2007). Most of these initiatives aim to produce XML (eXtensible Markup Language (Bray et al. 1998)) schema which define an encoding of agricultural data using text structured using machine- and human-readable markup ('tags') indicating the meaning of each data item. Where data are held by multiple organisations and/or in a distributed system, such a file-based data transfer is sub-optimal as often only one particular data value or information related to a particular object is required and it would therefore be preferable to be able to retrieve only this information on-demand, rather than a whole file, particularly as the exact set of information to be retrieved may not be known in advance. As we show in the use-cases considered later in this paper, exchange of data among organisations also plays an important role in precision agriculture. A Service-Oriented Architecture (SOA) by which data can be exchanged on-demand using web services with standardised interfaces and data transfer formats therefore has a role to play in the optimisation of data flows in PA.

Web services

Web services provide the functionality of standard computer systems via a network interface. It is important to distinguish web services from web pages and web-based applications; the latter two are intended to be accessed by a human user using a web-browser whereas web services are intended to be accessed by specialist client software. This client may in turn be part of a web-based application or even a 'cascading' web service, or it may be a standard desktop computer application. Web services are usually implemented to be self-describing whereby a client can automatically determine what functionality and/or data is available from a particular service. In practice, web services are usually implemented to use XML both for describing the interface and for data transfer, often using a general standard such as the Web Service Definition Language (WSDL—Christensen et al. 2001) for the former and the Simple Object Access Protocol (SOAP—Gudgin et al. 2003) for the latter. In a Service-Oriented Architecture, each service provides specialised data or functionality, creating networks of applications owned and managed by many organisations. This inter-operability is supported by accepted standards and a pervasive network technology connecting every component (including servers, desktop clients and mobile clients such as laptops, cellphones or on-board computers) to the internet via a wired or wireless connection (Curbera et al. 2003).

The application of web services to the agricultural sector is not new. For example, Spilke and Zürnstein (2005) highlight the potential of web services for data transfer between partners in agriculture as well as for application integration including external service providers. Casadesus et al. (2007) consider the architecture requirements for an SOA for sensor-controlled irrigation. However, it has long been recognised that the ability to efficiently handle geospatial data, as is required for PA, requires that specialised systems be developed (Egenhofer 1993). This also makes web services for geospatial and PA data more complex than standard web services for business transactions (Tu and Abdelguerfi 2006). The geographic information community recognises the requirement for specialised geospatial web services, with standardisation of these being one of the main goals of the OGC.

OpenGIS standards

OpenGIS standards are developed by the OGC, a worldwide body with over 300 members from industry, government and academia. The OGC works closely with ISO/TC 211 'Geographic information/Geomatics', ensuring ISO-compatibility for OGC 'abstract specifications' and develops OGC industry-standards into ISO international standards. The OpenGIS standards are generic standards which may be used in many domains. Of particular interest for agricultural data flows are the standards for web services and transfer formats for geospatially referenced information, the most relevant of which are summarised later in this paper.

It should be noted that most OpenGIS interface specifications allow the client to specify the format and the co-ordinate reference system (CRS), from those supported by the server, in which the data is to be returned. Many problems of integrating data from heterogeneous sources are thereby greatly simplified. However, since the data may be held internally in a different format, reference system transformation problems, and therefore spatial mismatches, may still occur.

Whilst there may be disadvantages to using the OpenGIS standards for agricultural data flows since they are not designed specifically for this task and do not currently integrate with mainstream web-service standards (e.g. SOAP and WDSL), they have many advantages;

- a complementary set of already standardised multi-purpose interfaces and many implementations (both proprietary and open-source) are available,
- the spatial referencing of the data, particularly relevant to PA, is in the forefront of the OpenGIS standardisation efforts and, from a practical viewpoint, is available for use for querying to retrieve data on a part-field level,
- the interfaces conform to existing ISO- and industry-standards and are already in use over a broad field of applications,
- compatibility with more general web service standards is planned for the near-future for existing standards (see e.g. Duschene and Sonnet 2005a, b) and is already implemented in more recent specifications (e.g. Schut 2007),
- many base datasets such as topographic maps have already been made available using these standards as part of national and regional spatial data infrastructure initiatives such as the German 'GDI-DE' (Geodateninfrastruktur Deutschland, IMAGI 2009) or the EU 'INSPIRE' (Infrastructure for Spatial Information in Europe, EC, 2007).

Geography markup language

Geography Markup Language (GML) is currently in version 3.2.1, which is identical to ISO standard 19136:2007. GML is "an XML grammar written in XML Schema for the modelling, transport and storage of geographic information… GML provides a variety of kinds of objects for describing geography including features, co-ordinate reference systems, geometry, topology, time, units of measure and generalized values". (Cox et al. 2003). A feature in GML is defined as an "abstraction of a real world phenomenon" according to ISO 19101:2002. To apply GML, it is necessary to create an application schema (implemented as an XML schema) defining the features of interest within the application domain. Such application schemas have been defined, for example, for city models (Gröger et al. 2006) and transport (Cambridge Systematics, Inc. et al. 2006). GML would also serve as a good basis for standardising data formats for PA (Korduan and Nash 2005). In this context, a feature could correspond to a farm, a field, a soil sample or a single-point yield measurement.

Web map service

The Web Map Service (WMS) interface "produces spatially referenced maps dynamically from geographic information. It specifies operations to retrieve a description of the maps offered by a server, to retrieve a map, and to query a server about features displayed on a map" (de la Beaujadiere 2006). WMS 1.3.0 was approved as an ISO standard in 2005 (ISO 19128:2005). Note that WMS "is applicable to pictorial renderings of maps in a graphical format; it is not applicable to retrieval of actual feature data or coverage data values" (de la Beaujadiere 2006). In the context of data flows in PA, WMS is therefore most likely to be used for retrieval of background imagery (topographic mapping or orthophotos) or for producing a human-readable summary of data.

Web feature service

The Web Feature Service (WFS) "allows a client to retrieve and update geospatial data encoded in Geography Markup Language" (Vretanos 2005). The current version is 1.1.0, with an ISO version (ISO19143) scheduled to be published in 2009. The basic WFS allows for the retrieval of features including vector geometry, with transactional extensions for insert/update/delete operations defined as WFS-T). Queries are specified using Filter Encoding, effectively an XML encoding of SQL-like operations including spatial and topological extensions. Whilst a WFS must offer data as GML, other vector-based formats may also be offered, allowing existing branch-specific formats such as agroXML to be used. A typical usage of WFS in an agricultural context may be for retrieving yield data from an agricultural process data service (APDS—Steinberger et al. 2006) or soil sampling results from a contractor's server, whilst WFS-T would allow upload of, for example, contracts including spatially referenced information such as location-specific fertiliser quantities.

Web coverage service

The Web Coverage Service (WCS) provides the functionality of the basic WFS for raster-gridded data, effectively extending the WMS to provide not only a portrayal of the data (i.e. RGB-images) but the actual data values themselves, e.g. as a multi-valued GeoTIFF or ArcInfo/ASCII Grid. The WCS is a suitable interface for delivery of remote-sensing data or interpolated maps (yield, ECa, etc.) where actual data values and not just a simple graphical representation are required.

Web processing service

The Web Processing Service (WPS) offers "any sort of GIS functionality to clients across a network, including access to pre-programmed calculations and/or computation models that operate on spatially referenced data" (Schut 2007). The final v1.0.0 WPS standard was released in 2008 and defines an interface by which distributed geo-processing may be delivered. This may be standard GIS functionality such as map algebra (Kiehle et al. 2006), buffering (Heier and Kiehle 2006) or spatial joins (Stollberg et al. 2007) or more specialised functions such as generation of fertiliser application maps or sub-field management zones (Nash et al. 2007). The WPS is notable for being the first OGC specification to include a SOAP/WSDL option, facilitating inter-operability with generic, non-geospatial web services.

Sensor web enablement (SWE)

"The OGC's SWE initiative is focused on developing standards to enable the discovery, exchange, and processing of sensor observations, as well as the tasking of sensor systems" (Botts et al. 2006). Almost all aspects of the use of networked sensors are covered in the SWE, e.g. the Sensor Model Language (Sensor ML) for discovery and tasking of sensors, TransducerML to describe individual sensors and the Sensor Observation Service (SOS) for retrieval of observation data. Additionally, alerting (SAS), planning (SPS) and notification services (SNS) are also under development. However, the communication 'behind' the service interfaces is not defined, i.e. how the data transfer between the sensors and a SWE service gateway is managed is not standardised, allowing any one of a range of

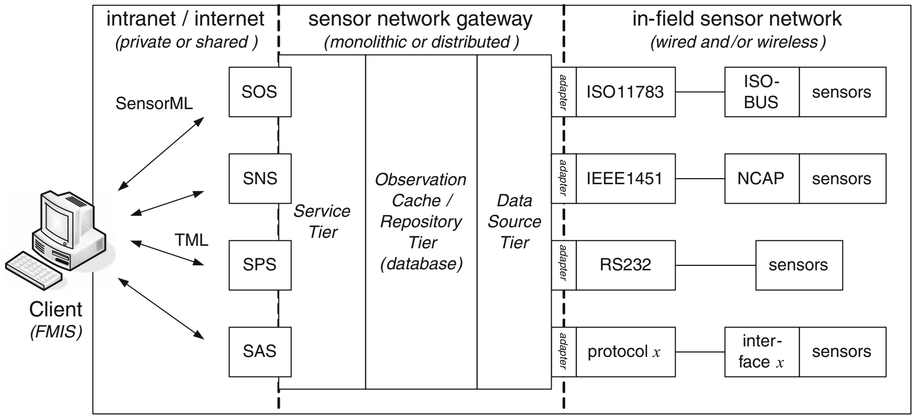

Fig. 1 Potential roles of SWE and other sensor standards in a (wireless) sensor network for precision agriculture (adapted from Botts et al. 2006)

standards or proprietary protocols to be used for communication in the 'in-field'network for controlling sensor nodes or transferring measurements to the sensor network gateway (Walter and Nash 2009). The SWE initiative could therefore provide a software 'middleware' layer for all networked sensors, and is designed to harmonise with other areas of sensor standardisation such as the IEEE 1451 network-capable application processor (NCAP) 'smart transducer' interface (Fig. 1). Particularly with regard to the current interest in wireless sensors (e.g. Kim and Evans 2009; Lokhorst et al. 2008; Morais et al. 2008; Pierce and Elliot 2008; Vellidis et al. 2007; Wang et al. 2006), the SWE standards may have an increasingly important role to play in managing and integrating real-time and continuous data collection for precision agriculture.

Other specifications

This summary only details what we consider to be the most important standards for the PA sector; the OGC has produced many other specifications which are of relevance. The Catalogue Service for the Web (CS-W) and accompanying profile of ISO standards for geographic metadata provide mechanisms for users to discover available services and datasets. Standards for security of OGC web services are also currently under discussion and, given security and data ownership concerns of farmers as reported in Fountas et al. (2005), will undoubtedly play a future role in the usage of web services in agriculture.

Automating data flows in precision agriculture using OGC web-services: use cases

In order to demonstrate the concrete application of inter-operable web services described above for PA, a use-case based approach has been taken. This involves identifying and modelling typical workflows, particularly with regard to the data flows so that standardised interfaces and data transfer formats could be applied. Three such use-cases are presented here, illustrating the use of a variety of OGC standards. Note that although these use-cases present a single work-flow, this should not be taken as a requirement to standardise the workflow, rather that variations on these workflows will display similar data flows and thus similar interfaces may be used to support them.

Soil testing

Soil testing to determine properties of the soil such as nutrient content and pH is a standard task in PA which would be repeated on a semi-regular basis (e.g. approximately every 3 years) to provide a base dataset for calculating fertilisation levels. We here assume that the farmer has significant experience in PA and takes the lead role in planning the testing, including determining the locations for probes. Less experienced farmers may just specify the boundary of the area to be tested or general regions in which the test sites are to be located: this still requires the transfer of a contract containing spatially referenced information, albeit at a lower resolution.

We assume that the farmer requires up-to-date large-scale geological- (e.g. upper soil type or class) and topographic mapping in order to complete the planning. This is, in this case, made available using the WMS interface: alternatively, a satellite image or orthophoto may be used. Note that many GIS packages now integrate the required client software for this interface and many agencies offer their products over WMS on a subscription basis or for free (albeit sometimes only for private or internal use): e.g. NASA satellite data via OnEarth (NASA 2009) or mapping and aerial imagery from Mecklenburg-Vorpommern via GeoPortal.MV (LAiV 2009).

Once the farmer has planned the test sites, a contract for the testing is passed to a soil-testing consultant. This transfer may be automated using an appropriate agroXML document and an upload to the consultant's server via the WFS-T interface. The consultant may then access the details of the contract and, again via WMS, retrieve the background mapping necessary to successfully carry out the testing, before making the results available for download by the farmer over WFS, again in agroXML format. The farmer can then integrate these results into the FMIS, which should incorporate an appropriate client module.

As a use-case for inter-operability, this illustrates the requirement to be able to access up-to-date background mapping from a variety of sources in order to plan the soil testing and to be able to transfer spatially referenced agriculture-specific data between a farmer and a consultant or other organisation. The use of web-services for this part enables an automated transfer of information between the farmer's and the consultant's software, meaning that all information must be entered only once, reducing the risk of errors and increasing the traceability as well as decreasing the time required. The activities and interfaces within this use-case are illustrated using the standard Unified Modelling Language (UML) in Fig. 2, within which horizontal lines may be read as being a data flow between actors. The annotations in roman type indicate how this data flow may be implemented using OGC and complementary agriculture-specific standards.

Calculation of a nitrogen fertilisation application map

There are many possibilities for calculating the total required nitrogen fertilisation for a crop (N_{total}). We here wish to demonstrate the possibility of implementation using web services and thus have used a simplified algorithm considering nitrogen removal by the preceding crop (N_{removal}) and the soil mineral nitrogen content (N_{min}): $N_{\mathrm{total}} = N_{\mathrm{removal}} - N_{\mathrm{min}}$. The data sources in this case are therefore the APDS (agricultural process data service) to which a contractor has uploaded the raw yield data gathered by the on-board machinery, and which makes the cleaned and pre-processed data available in agroXML format via a WFS interface (Steinberger et al. 2009), and a soil-testing consultant's server making test data available, again as agroXML via WFS.

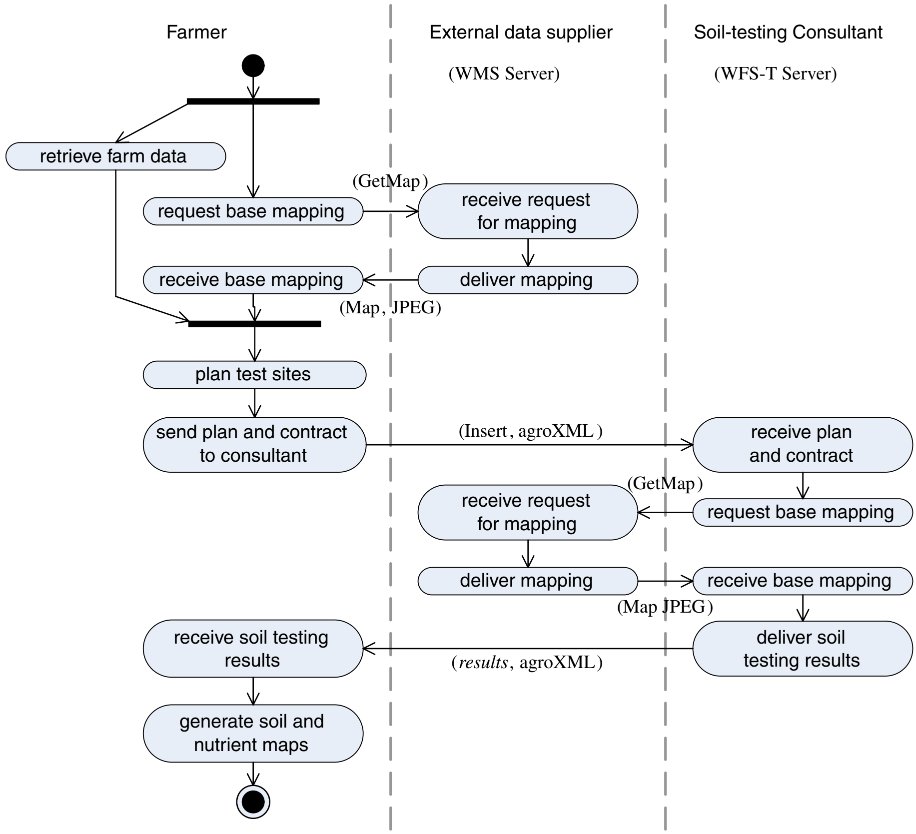

Fig. 2 Annotated UML activity diagram showing data flows in the use case "soil testing"

Figure 3 shows an implementation of this algorithm using chained WPS servers to implement each individual stage of the calculation. The raw yield data is retrieved from the APDS and normalised to 14% moisture before $N_{removal}$ is calculated, based on the protein content if available or using estimated values if not. These individual point-values are then interpolated to a raster. Meanwhile, the soil test results (N_{min}) are retrieved from the consultants' server and interpolated. Finally, the two interpolated datasets are subtracted. This whole process is distributed between 5 WPS servers, although only one is visible to the FMIS, which acts as a thin client for the farmer to enter the required parameters and display the resulting fertiliser application map. The parameters are URLs of the WFS services and the year for which to retrieve yield data, the crop type and the boundary of the area of interest. The URLs and harvest year may be replaced by the actual datasets if they are stored locally, removing the WFS calls.

This use of distributed processing and data storage capabilities allows flexibility in the development and deployment of new algorithms: the required generic and specialist processing services can be discovered and the chain composed to implement a new algorithm made available via a single server-managed service chain without requiring any changes in the client software, particularly if it is capable of using the provided process metadata to find new processes and generate an interface for setting the required parameters. The

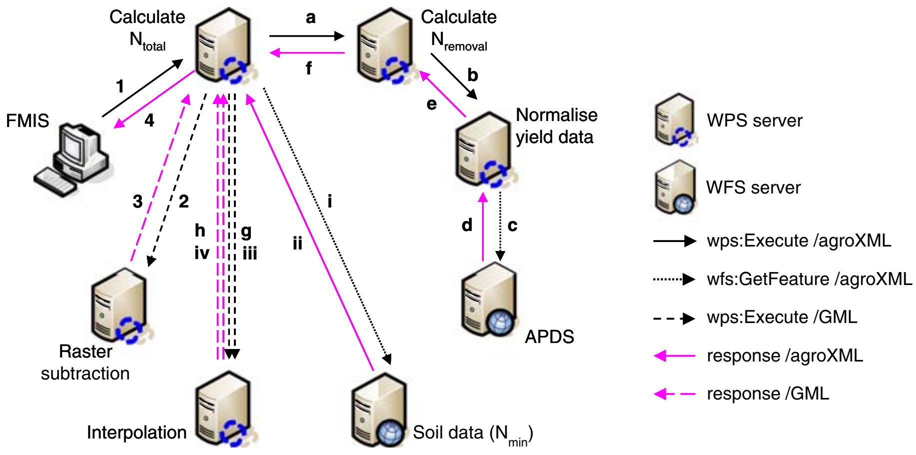

Fig. 3 Implementation of an algorithm to generate a total nitrogen fertilisation application map using distributed OGC services. The flow of control is 1, a–h/i–iv, 2–4 with a–h and i–iv being run in parallel

distribution of the processing tasks and data storage also allows the FMIS or other client to be run on a low-spec computer such as a mobile device.

Decision-making for irrigation

With this scenario, we wish to demonstrate how the SWE standards may be used for access to both remotely- and locally-collected sensor data as part of a decision-making process for irrigation. The general use and advantages of a SOA using in-field sensors and external data for irrigation, including automated decision-making and implementation, is shown in Casadesus et al. (2007). We wish to highlight where open geospatial web services may help optimise the SOA. We assume manual decision-making and control where the farmer will make a decision as to the required level of irrigation. We also assume this decision is based on a combination of soil moisture data collected continuously using an in-field wireless sensor network and regional weather station/forecast data. We further assume the farmer will manually operate or programme the irrigation system, although an extension to a fully automated system would of course be possible, provided the decision-making logic could be sufficiently well defined.

The weather data may be provided by an external commercial provider, or may be collected locally. In the latter case, a group of farmers may be able to pool resources and share weather data via a communal web server in order to increase the volume and reliability of data and reduce costs.

The wireless sensor network for monitoring soil moisture may be connected to an on-farm server via a local gateway, which may then be connected either hard-wired or wireless to the farm network (Fig. 4). In this way, the transmitter- and energy-requirements of the individual wireless sensors are minimised. We assume that the communication in the 'in-field' part of the network from the individual sensors to the respective data servers would use appropriate proprietary protocols or standards such as IEEE1451, IEEE 802.11 WLAN/WiFi (e.g. Lokhorst et al. 2008), Bluetooth (e.g. Kim and Evans 2009), Zigbee (e.g. Morais et al. 2008) or, for agriculture-specific sensors, the ISO11783 family (ISO-BUS) may also be used in wireless networks as has been shown by Goense et al. (2005).

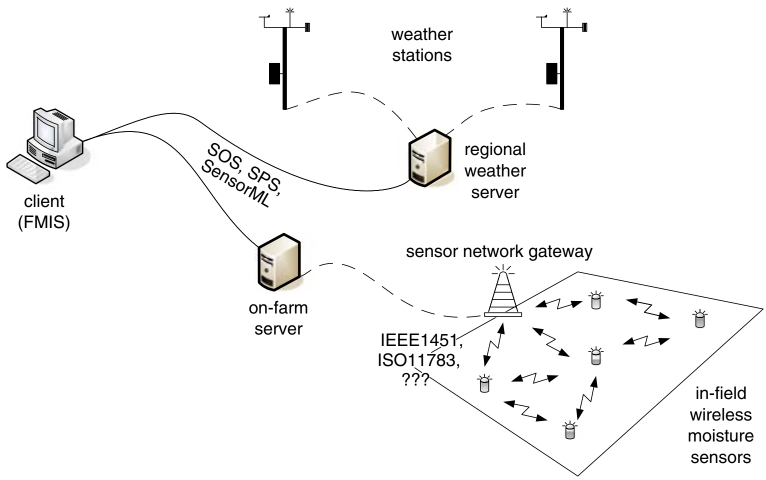

Fig. 4 Use of SWE and other standards in a sensor network for decision support for irrigation

The role of the SWE standards is to provide a high-level interface to the sensor networks, including aspects such as spatio-temporal referencing and querying of sensor data. Rather than the client software (FMIS) needing to communicate individually with each sensor or sensor network, the OGC Sensor Web Enablement standards stack allows the observed values, even from multiple sensor networks, to be retrieved and potentially aggregated, without needing knowledge of the potentially diverse and proprietary protocols and data formats used by individual sensors or even prior knowledge of available sensors and their types and locations.

Open questions

If the potential use of OpenGIS technologies in agriculture is to be realised, further work is required on integrating them with agriculture-specific standards. As an example of the current problems, during the implementation phase of the first two use-cases presented here, only one WFS package was found capable of handling agroXML, and even this required a significant amount of configuration and customisation. To support a widespread uptake of these technologies, it may be necessary, as well as the sharing of best-practice examples, to develop a specialised 'Open-Agri' toolkit providing pre-configured support for agriculture-specific standards in the context of OpenGIS services. Reliability and flexibility in service chaining for processing services also require further research—the implementation described in the second use-case above is statically chained which means that if one server is unavailable the workflow cannot run. An ideal solution would see dynamic discovery and chaining of services to fulfil the workflow, also allowing new workflows to be dynamically generated to implement other algorithms. Such workflow management is currently receiving research attention (e.g. Hobona et al. 2009a) and solutions are therefore likely to become widely available in the near future.

Furthermore, the integration of agricultural sensors with the Sensor Web Enablement standards stack is currently untried. The authors' general experience is that wireless sensor networks and gateways do not directly support any elements of the SWE standards, usually only providing data in a proprietary manner. Converting the data from such WSNs to a SWE-compatible format is not a trivial task. However, this problem does not apply solely to agricultural sensors, and solutions such as a 'SWE connector' (Walter and Nash 2009) to enable the linking of proprietary WSNs to SWE services with a minimum overhead are currently under discussion.

Finally on the technical front, issues surrounding security and data protection must also be resolved before such technologies are likely to see a large-scale uptake. Most of these issues are being discussed in the wider field of geographic information and web-service research, but the applicability and acceptability of the solutions being developed to PA must also be addressed. For on-farm servers, an access restriction to the local intranet may be sufficient, but for shared servers or for transfer of data to external servers, each farmer must be confident that their data may only be accessed by the relevant bodies, is secure during transit and will not be made available to third parties from the remote server. Such questions of course apply to any network-based transaction, and authentication (e.g. Shibboleth (Internet2 2009)) and encryption (e.g. SSL (Freier et al. 1996)) technologies are already available, with work currently ongoing to integrate these with OpenGIS services (e.g. Hobona et al. 2009b). The general concept of a SOA for agriculture, not necessarily based solely on OpenGIS services, is also being widely developed (e.g. Heer et al. 2009, Murakami et al. 2007). Coupled with the movement of OGC standards towards harmonisation with wider standards for web services (e.g. Duschene and Sonnet 2005a, b), it is therefore likely that these general questions will be addressed both in the context of agriculture and of OpenGIS services in the near future.

The introduction of a service-oriented architecture does not however only require that technical challenges are overcome—the definition of an SDI as given by the International Journal of Spatial Data Infrastructures Research includes "frameworks of technologies, data, policies, institutional arrangements, and people" (IJSDIR 2009). Until now the main impetus for development of SDIs and provision of geospatial data services has come from governments (provision of data) and research (processing and sensor web enablement). Topographic mapping and satellite and aerial images are therefore already fairly widely available over Web Map Server interfaces. Although the trend for provision of data, particularly within the bounds of international and national SDI projects, may be expected to continue, it is unclear which organisations may provide specialist services for agriculture. Furthermore, Web Feature Service and Web Processing Services as described in the use-cases presented in this paper are not currently publically available. Particularly where the business model for providing a service is unclear then commercial entities are unlikely to be motivated to do so. Where simplification of business processes crossing the farm boundary may be expected (as in the soil-testing use case presented here) then the individual consultants or other organisations may provide the services. Particularly where the partner is a government organisation (e.g. for subsidy applications) then it may be possible for this to force the adoption of a particular standard, whereas commercial providers operating in a competitive environment where there is no monopoly position may find this impossible.

Ultimately, the suppliers of agricultural software products must be in the front line of adoption of service-oriented technologies in order to provide farmers with the required client software. Since these are also commercial entities, the benefits for the software providers in terms of increased functionality and therefore market share must be apparent before this is likely to happen. This requires both agreed standards in order to ensure interoperability and a critical mass of services and service providers to ensure a viable 'ecosystem' for an agricultural data infrastructure. Although, as many industry-led standard initiatives demonstrate, common commercial interests may lead to the adoption of standards, the mandating of particular standards by governments is likely to lead to quicker adoption of any particular standard, not least because all farmers are likely to have contact with these, whereas only a subset of all farmers will have contact with any one commercial body.

In order for farmers to access the services required, they must know the URL of the server. Since data is made available on a national or regional basis, these URLs should therefore also be published at this level. Although national and regional portals and geospatial data catalogues are being made available, it should not be assumed that farmers will know of these or wish to use them. One potential solution is that the software suppliers, who often work within national or regional markets, will be able to pre-configure the software with the addresses of relevant services for each farmer (perhaps as a drop-down list or similar from which the farmer may choose which service to access). Additionally, the addresses of web services may in future be widely publicised directly by the service suppliers or indirectly through agricultural advisors, in the same way as informational websites are currently publicised. Alternatively, the FMIS may include a catalogue service client integrating the search for services into the farmer's software, potentially allowing relevant new services to be automatically discovered. In any case, the discovery and use of services should not place a great additional burden on farmers and so the inevitable complexity should be largely hidden by the FMIS.

Conclusion

This paper has presented the OpenGIS standards as a means of creating inter-operability between software for handling geospatially referenced PA data. The perceived advantages of using the OpenGIS standards for web services, rather than the more generic SOAP/WSDL model, are

– that the spatial aspects, which are particularly relevant for PA, are at the forefront of these standards,
– that a large number of standards are already available to cover many aspects of geospatial data transfer, and
– that many of these standards are already in use by organisations supplying data for PA.
– A convergence of the OpenGIS standards with other industry standards is also foreseeable in the near future, which should further enhance their acceptance in the wider IT industry.

Three use-cases were outlined in which OpenGIS web-services could be utilised to automate data flows. These illustrated some of the many potential applications of such services in precision agriculture, such as accessing base data, transferring spatially referenced data either between partners in an agricultural business workflow or between software running geospatial and/or mathematical models, or as a high-level interface to (wireless) sensor networks.

Finally, some of the open questions which must be addressed before widespread adoption of OpenGIS and web service technologies in agriculture is likely were discussed. Many of these questions are also research themes in wider research communities but, in particular, the questions of adoption of standards for web services and geospatial data transfer for precision agriculture must be addressed by the agricultural community itself.

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