Distributed System Architectures, Standardization, and Web-Service Solutions in Precision Agriculture

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Abstract—**Effective precision agriculture requires the gathering and managing of geospatial data from several sources. This is important for the decision support system of automated farming. Distributed system architecture offers methods to combine these variable spatial data. We have studied architectural and protocol choices of distributed solutions and built up a demonstration implementation of the system. As one of the key factors of the system is interoperability, we applied standards for geospatial and agricultural data, a location-based service platform, and a technology of geosensor networks in the implemented system. We successfully demonstrated the interoperability and scalability requirements and functionality of the implemented system.**

Keywords- precision agriculture; spatial data; interoperability; distributed system architecture

I. INTRODUCTION

In automated farms, agricultural operations and processes are planned, executed, monitored, and assessed with the help of spatially referenced data. Spatial variability and changes in production conditions can be monitored by specific sensors, and thus can be taken into consideration when production inputs of precision agriculture (PA) are planned and executed. However, the realization of any expected higher productivity requires that decision-making and farming operations are based on spatial data of good quality and accuracy. Effective use of data also necessitates that data originating from internal (farm equipment and software) and external data sources (e.g., meteorological data) can be easily integrated and transferred between different hardware, software, and information systems [1][2]. Besides this, a refined and integrated analysis of the data acquired and the transformation of these data into information and knowledge useful for decision-making are also required [3].

The many existing data acquisition systems, documentation tasks, and precision farming applications result in a variety of data formats and interfaces, making data management complex in PA [1]. In addition to limitations in data exchange and communication between incompatible systems, lack of time, knowledge, or motivation of farmers to evaluate data from PA are among the key problems in data management, and result in great demand for automated and time-effective expert systems for the handling of precision farming data [3]. Because PA requires external services and cooperation with many partners, interaction and sharing of spatial data between a farmer and stakeholders must also be provided. Instead of data format conversions, coordinate transformations, and other forms of manual processing of heterogeneous data, effective information management is currently based on web-enabled spatial database systems, providing one of the most interoperable environments for distributed computing [4].

The purpose of the system design presented in this paper is to develop and implement the acquisition, storage, transfer, and management of spatial data produced in various operations of PA. In addition, one of the purposes is also assure the quality of spatial data by utilizing appropriate standards: ISO 11783 in agricultural vehicles and OGC's (Open Geospatial Consortium) standards in wireless soil measurements. The development of the system is inspired by the architecture of a farm management information system (FMIS) designed in a Nordic project, 'InfoXT' [3]. We applied a location-based service platform and a technology of geosensor networks in the development of the system with the aim to demonstrate interoperable solutions for the FMIS. Implementation of communication and data interchange in the system is based on geospatial standards such as WFS

(Web Feature Service), SensorML (Sensor Model Language), GML (Geographic Markup Language), and BXML (Binary Extensible Markup Language). Our previous experiments of BXML, SensorML, and ISO 11783-based data transfer are utilized in the development work.

In Section II, the main technologies and relevant standards related to distributed systems in agriculture will be discussed. Developing this kind of distributed system especially requires expertise related to location platforms and geosensor networks. Based on this introduction, the use of chosen standards will be further explained in this paper. Section III introduces the demonstration implementation of the system. The conclusion and future work are presented in Section IV.

II. RELATED WORK

In order to automate agricultural operations and processes we will need to build systems that are able to collect data from machines and from the field. Geosensor networks are among the new technologies that can be used to monitor agricultural phenomena. The technology is under intensive development and its application possibilities are gradually widening. Geosensor networks present a multidisciplinary research area, combining such fields as geoinformatics, computer sciences, telecommunications, and sensor technologies. Nittel et al. [5] have defined geosensor networks (GSN) as a sensor network that monitors phenomena in geographic space. This geographic space can range in scale from confined indoor conditions to highly complex outdoor environments.

Location platforms can be classified as device-centric, decentralized middleware-based, and centralized platforms [6]. Location-based service platforms can be considered as one form of distributed Geographical Information Systems (GIS). A distributed GIS can be defined as a network-centric GIS tool that uses a wired or a wireless network for providing access to distributed data, disseminating spatial information and conducting GIS analysis [7].

The main actors in this research field have been the Open Geospatial Consortium (OGC) research network and the National Aeronautics and Space Administration (NASA). According to OGC [8], their OpenGIS Interface Standard defines OpenLS Core Services, which form the Services Framework for the GeoMobility Server (GMS). These services cover Directory Service, Gateway Service, Location Utility Service, Presentation Service, and Route Service. GMS, as a location services platform, hosts not only these services but also Location Content Databases accessed through OGC Interfaces such as Web Map Server (WMS) and Web Feature Server (WFS). WMS produces maps of spatially referenced data dynamically from geographic information in a raster graphic format such as PNG (Portable Network Graphics), GIF (Graphic Interchange Format), or JPEG (Joint Photographic Experts Group), or in a vector graphic format, e.g., in SVG (Scalable Vector Graphics) format. Moreover, WMS generates a map when requested from spatial data stored in GML format, which is an XML (Extensible Markup Language) grammar for expressing geographical features [9].
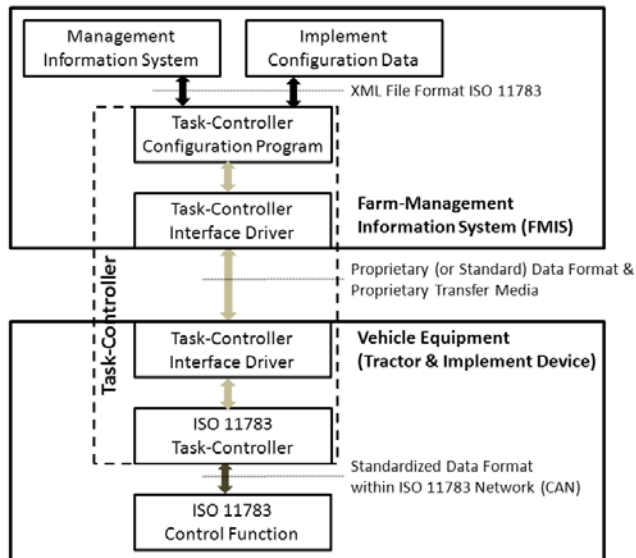

Figure 1. ISO 11783 [13] Task-Controller interfaces and transfer methods.

For geosensor networks, the main part of OGC's work is made under Sensor Web Enablement (SWE), which is a suite of specifications related to sensors, sensor data models, and sensor web services. The goal of SWE services is to enable sensors to be accessible and controllable via the Internet [10]. SWE consists of Observations and Measurements Schema (O&M), Sensor Model Language (SensorML), Transducer Markup Language (TML), Sensor Observations Service (SOS), Sensor Planning Service (SPS), Sensor AlertService (SAS), and Web Notification Services (WNS). XML is a key part of this infrastructure and all the services and content models are specified in XML schemas [11].

NASA has used OGC's SWE specifications in their geosensor networks and sensor web applications. Their EO-1 sensor web architecture is currently being updated to support an interface standard in development by the SWE group. This Earth Observing-1 Mission has been operating an autonomous, integrated sensor web linking dozens of sensor nodes in 24/7 operations since 2004. The use of sensor web technologies has been very successful with a number of cost-effective impacts on maintenance. These sensor web technologies have been used in the National Snow and Ice Data Center, and in the Cascade Volcano Observatory. In the first case, these technologies were applied to track ice formation and melting and use this information in EO-1 analysis. In the latter case, the goal was to acquire high-resolution infrared data of Mt. St. Helens [12].

An important standard for precision agricultural solutions is the so-called ISOBUS standard, i.e., the ISO 11783 standard family. The main focus of this standard is to define the bus and the control processes used in tractors and machinery for agriculture and forestry. It enables the hardware compatibility of tractors and different agricultural implement devices such as seeders, fertilizers, and harvesters. In addition, Part 10 [13] of the standard defines the data interchange between the farm management information system and the task controller (TC) process of

the vehicle (tractor and implement device). The standard precisely defines the standardized data transfer and data transfer file in the XML format. According to the standard, the task controller is physically divided between the FMIS (farm management information system) and the vehicle. The ISO 11783 standard does not define the actual transfer media and the data format can be either a proprietary or a standardized data format. Figure 1 shows the proprietary version of data transfer where some parts of the Task-Controller are situated within the FMIS-subsystem instead of entirely at the vehicle equipment. The standardized option means that the ISO 11783 XML files are used in transferring between FMIS and vehicle equipment. In both options, the actual transfer media can be cable, transferable memory device, or some radio communication method.

The transfer of the actual XML files is not desirable when wireless radio communication methods are used since the larger data amount has the disadvantage of increased operational costs or a disturbingly long time spent on the data transfer. In our previous study [14], we have demonstrated the data transfer between FMIS and vehicle equipment using the radio protocol of IEEE 802.15.4 standard [15] and a compressed data format that is truly proprietary. The binary format XML compression methods based on the OGC's SensorML standard and BXML, the best practices specification [16][17] demonstrated in [18], are achievable for this purpose. Our suggestion is to use the compressed XML data format to achieve convenient wireless transfer media while simultaneously minimizing resource and cost requirements.

III. IMPLEMENTATION OF THE SYSTEM

The system is implemented utilizing a location-aware system platform called Locawe that is developed at CENTRIA Research and Development, Ylivieska, Finland. The architecture, the use of geosensor network-related standards, several field experiments, and industrial pilots related to this platform have been introduced in [18][19]. The Locawe platform is a client-server solution for outdoor and indoor conditions. This platform consists of mobile units and
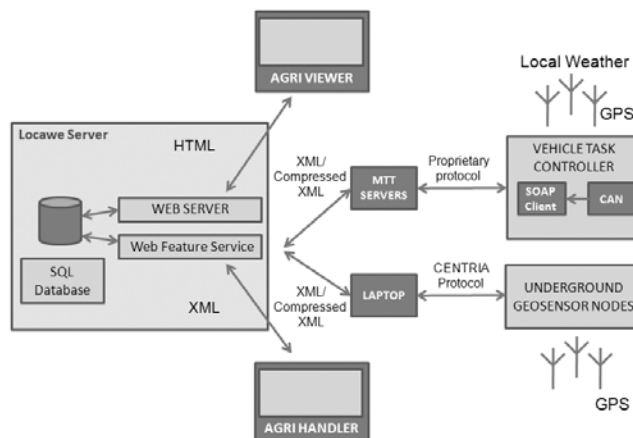

Figure 2. The use of GSN nodes with mobile devices in the Locawe Platform in previous studies.

Figure 3. Agricultural sensor data delivery from various sources by utilizing OGC's WFS.

servers for services like tracking and communication. It is possible to create user interfaces, which include video, location, and identification information on the map or on the floor plan [20]. In our previous experiments in agriculture reported in [14][18], the communication between GSN nodes and mobile devices was in a binary format based on OGC's SensorML standard and BXML best practices specification [16][17] (Fig. 2).

Figure 3 shows the implementation of the distributed system architecture. In the Locawe server, OGC's WFS standard acts as an interface between the SQL (Structured Query Language) database and applications. WFS messages contain basic XML definitions and action determinations. The data needed for executing queries are implemented in XML format, which can contain, e.g., GML type definitions. WFS requires login action to recognize user rights, which will determine what kind of queries the user can do. WFS manages the SQL database and correct data format. WFS messages can contain images in raw byte format or vector data in GML format.

We demonstrated the interoperability of the system by delivering spatial agricultural data to the server from various sources. The WFS interface manages data delivery from an underground geosensor network to a laptop as a gateway. It also handles data delivery to the Locawe server from the vehicle task controller via the servers of MTT Agrifood Research Finland. Spatial harvester data collected by MTT were also used as data in the demonstrations of AgriHandler and AgriViewer applications.

A. Underground Geosensor Network

The main focus of the implementation of this study was the demonstration of architectural and protocol choices. The design of equipment of soil property measurements was beyond the scope of this paper. The proof of concept type and validation measurements were performed with wireless sensor nodes, which were neither optimized nor actually aimed for soil measurements. Our wireless sensor nodes used the 868 MHz frequency band version of the IEEE 802.15.4/ZigBee standard with the power level of 11 dBm. According to [21], this ISM (Industrial, Scientific, and
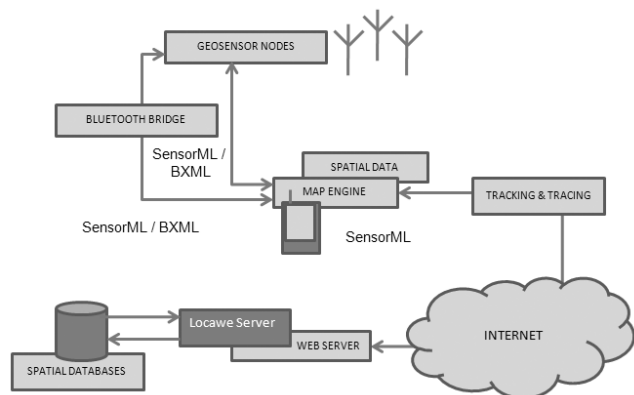
Medical) frequency band is the most suitable and practical compromise solution for wireless soil measurements. The wireless sensor nodes were underground at a depth of 30 cm. In our validation measurements, the range of 28.5 meters was achieved with favorable conditions, i.e., with relative low soil moisture. The long-term measurements of actual wireless underground soil scout prototypes are reported by [21][22]. These measurements showed that soil attenuation has a strong dependence on soil moisture.

Underground sensor nodes give measurement values to a main node device that is connected to a laptop. This PC and the main node communicate using a proprietary structure called the CENTRIA Protocol. It is designed for use in communications with low-rate devices. The used geosensors do not have any locating property, but the location of the sensors on the field can be set by the user with help of the developed PC software. For absolute location, the coordinates collected by a GPS (Global Positioning System) device on the field must be inserted in the PC where the application will use them automatically.

B. User Interfaces

The demonstrated system has two applications as user interfaces for the database. AgriHandler application (Fig. 4) enables administration of farm and field data in the database through the WFS interface. Depending on user rights, the AgriHandler application can act as administrator tool or data handler tool with lower rights. An idea of the development of the application is to demonstrate how handled and analyzed precision farming data, e.g., interpolated nutrient balance maps, could be provided for a farmer (customer) as external information services. The quality and usability of handled and analyzed data is better compared to raw data. As a service provider, a data handler can get information to a local file and update the information in the database with the analyzed spatial data by messages over HTTP (Hypertext Transfer Protocol) POST to the WFS interface.
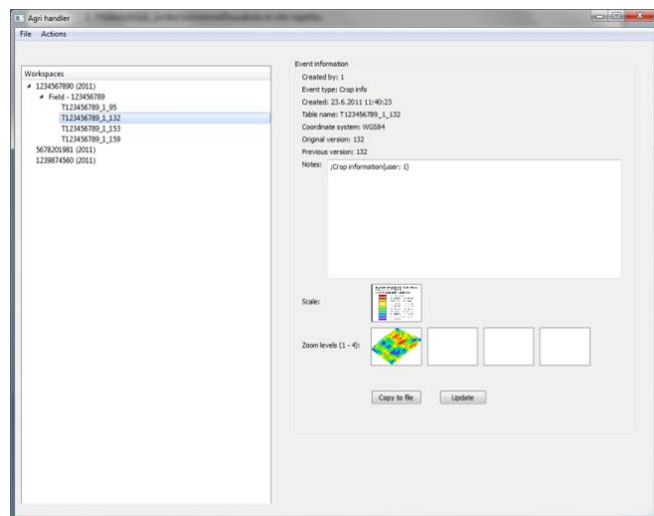

Figure 4. AgriHandler application showing the event information.

Figure 5. AgriViewer web application showing basic information and analyzed data related to the event.

These collected data of information (events) have own database tables and when the coordinate system is changed, a new table will be generated in the database. Inheritance of the events was taken into consideration in the database design. The application was demonstrated with crop yield data as vector points (MIF - MapInfo Interchange File) and images (PNG). The application also enables administration of geosensor network data. At the moment, AgriHandler supports WGS84 and ETRS-TM35FIN coordinate systems.

In the AgriViewer web browser (Fig. 5), end-users are able to view the same data explained above. The WFS interface is used only in authentication. Users have read-only rights in this web application.

C. Vehicle Task Controller

Dependable and efficient wireless communication may be challenging in mobile plant production in rural areas. However, this is an essential element in an approach where the assisting services supporting farming activities and knowledge management are based on a cloud computing paradigm.

In this demonstration (Fig. 6), the TC simulation was implemented giving high priority to the mobile connectivity challenges. Data packet size makes a difference in low mobile band width regions. The data collection itself is driven by GPS clock frequency, which is 5Hz when the signal strength is acceptable. Our approach to the dead network region dilemma is based on an idea to adjust the data transfer rate (from the TC to the cloud service) according to the mobile connection strength. In practice, this means that one collected data sample (that is, one data row) is sent to the service in every GPS clock cycle if the mobile connection strength is acceptable. In the case of mobile
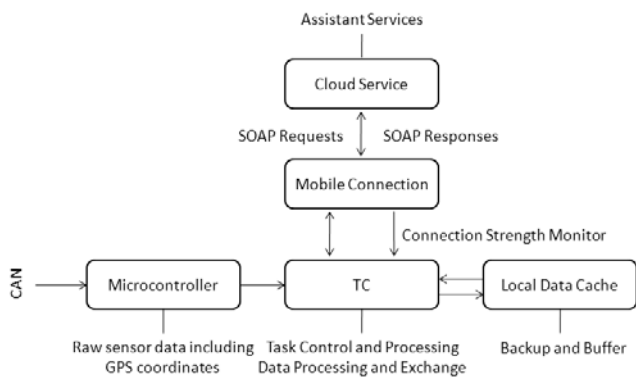
Figure 6.   Main actors in real-time data collection of mobile farming.

connection strength dropping below the threshold level, the TC starts buffering data locally. The transactions continue when the connection is restored again. In this way, also near real-time data transfer is achieved, an essential factor in implementing, e.g., real-time advisory services.

In this demonstration, the mobile connection monitoring element was excluded since the data collection and sampling were simulated. The transferred data samples were based on actual harvest data. Adequate data sample transfer rates from cellular (3G) and Ethernet network were achieved for, e.g., remote monitoring and advisory service implements.

The sample TC implement is simple yet powerful enough to handle SOAP (Simple Object Access Protocol) communication and the extensive parsing of XML documents required for SOAP requests and responses. The client was implemented without using any of the specialized Java SOAP classes and it is based on an article by DuCharme [23].

Architectural components consist of the following:
- Main class for handling the data transfer task
- Class for handling the SOAP requests and responses
- Class for parsing XML documents required for SOAP requests and responses
- Class for providing appropriate log in and log out request XML documents
- Class for simulating the microcontroller that provides the data collection functionalities from the sensors

Total compiled size is 18.7 kb.

A data transfer sequence starts when the client requests a session ID by sending a login request to the service. If username is authorized, the session ID for further SOAP requests is returned. After that, the main class creates a data-fetching sample provider object and begins transactions using SOAP requests called "insert crop info". A data transfer sequence ends with a log out request.

IV.   CONCLUSION AND FUTURE WORK

Basic functionality of the implemented distributed system architecture was demonstrated and tested. Interfaces were designed and implemented in such a way that requirements for interoperability and scalability were fulfilled. The use of chosen standards tackled both interoperability and quality requirements. Furthermore, in this paper the research focus was on proof of concept demonstration rather than actual performance evaluation. However, a full performance will be evaluated in a near-deployment phase.

In this demonstration, interoperability of the system was implemented with OGC's WFS interfaces, which managed delivery of spatial data as vector data and images. Besides the WFS interface, the implementation of the system could be developed further with OGC's Web Coverage Service (WCS) interface, which enables delivery of the spatial data in raster format.

Raw spatial data acquired in various operations of PA requires a lot of processing and analyzing before it can be utilized in decision-making. In the future, methods for automated handling and analyzing of spatial agricultural data should be developed to advance the information services provided for farmers. Implementation of the system architecture applying OGC's Web Processing Service (WPS) interface could provide functionalities for geospatial processing of data.

In the developed system, the usability of the graphical user interfaces was out of the focus. User acceptance and user experiences will be studied further in order to obtain applications that are fast and easy for farmers to utilize without special knowledge in the use of computers and databases.

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