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Prototyping the visualization of geographic and sensor data for agriculture

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ABSTRACT

The effectiveness of decision-making processes in the agricultural domain can be improved by integrating current local environmental and agromonitoring with the Geographic Information System (GIS) and wireless sensor networks (WSNs). The presented paper describes conceptual approaches to context-based cartographic visualization methods for agricultural and metrological data acquired by WSN and a portal prototype for integrated visualization.

Each sensor used for agricultural applications has a location and can be placed within a broader spatial context. In our study, sensor characteristics (soil temperature and moisture, atmospheric temperature and moisture) were automatically monitored at frequent intervals and these readings were aggregated with geospatial data from both local and remote (Web Map Service) sources. An experimental portal for the integration and visualization of sensor data and geospatial data was designed and prototyped on the basis of an open source interoperable platform. Conceptual approaches were successfully implemented on four experimental small-plot fields planted with different crop species and operated using different soil tillage practices. Experimental fields were situated in the southeast of the Czech Republic. Very Long range Identification Tag (VLIT) technology was used for wireless communication. Sensor observations verified differences in agrometeorological variables for the conventional tillage of soil and the no-tillage variant. Contextual cartographic visualization was successfully deployed for map view, dynamic cartographic symbology, and the dynamic measurement chart.

1. Introduction

The effectiveness of decision-making processes in the agricultural domain can be improved by integrating current local environmental and agromonitoring with the Geographic Information System (GIS) and wireless sensor networks (WSNs). The presented paper deals with methods of acquiring, processing, and visualizing sensor observations for agricultural applications. It summarises the main results of the Agrisensor project, which was focused on the development of a framework for accessing heterogeneous sensor data and services that support effective decision-making in the area of agricultural management.

The organization of this paper is as follows:

- Section 1 presents the concepts behind wireless sensor networks, Sensor Webs, and sensor data and their use in agriculture, as well as the concept of the cartographic visualization of sensor data, including adaptive visualization.
- Section 2 describes the Agrisensor project, its technological background, and the client developed for sensor data visualization.
- Section 3 presents the results from the testing of WSN and the development of the adaptive mapping environment.
- The last section summarises the main results and discusses the possible future development of the presented prototype application.

1.1. Wireless sensor networks and the Sensor Web concept

The dynamics of plant growth are related to the dynamics of environmental data, such as soil (or air) temperature and humidity and solar radiation, which can be measured using stationery local weather stations or wireless sensor networks (WSNs). WSN are a new technology that can provide processed real-time field data from sensors physically distributed in fields (Camilli et al., 2007). Akyildiz et al. (2002) described WSN as networks of small sensor nodes, including sensors and their specific conditioning circuitry, which have limited processing capacity and communicate over short distances, normally using radio frequencies.

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Isolated sensor networks are currently being integrated into a new internet-based concept – the so-called Sensor Web. Zyl et al. (2009) described this concept as an infrastructure that supports the vision of an integrated system of sensor systems or individual sensors, providing access to sensors, sensor networks, and corresponding observational datasets. The Sensor Web integrates heterogeneous sensors, both in situ and remote sensing devices, as well as stationary sensors or those attached to mobile platforms. From a purely systematic point of view, we can imagine the Sensor Web as an open, complex, adaptive system organised as a network of open access sensor resources (including both data and metadata), which exists within the Internet and provides external access to sensor resources.

1.2. Sensor Web applications in agriculture

Wang et al. (2006) presented an overview of recent developments in wireless sensor technologies and classified the applications in agriculture and food production under several categories. They identified environmental monitoring (weather monitoring, geo referenced environmental monitoring) and precision agriculture (spatial data collection, precision irrigation) as the most spatially dependent.

Environmental data are very important in agriculture, since crop yields depend on environmental conditions, and the response of plant growth to changing environmental conditions is extremely complicated (Lee et al., 2010). Feiden et al. (2011) focus on the harmonization and provision of interoperable soil geodata in Europe. Measurements of agronomical phenomena are required mainly for modern agricultural practices referred to as precision agriculture. The aim of precision agriculture is the optimization of production inputs (fertilizers, pesticides, fuel, etc.) based on local crop requirements and plant requirements. This approach to crop management can lead to the effective use of agrochemicals and the avoidance of environmental risks.

The main aspects of precision agriculture are described by Pierce and Elliott (2008). They define precision agriculture as "the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production for the purpose of improving crop performance and environmental quality". Assessing variability is the critical first step. The factors and properties that regulate crop growth and yield vary in space and time. The wider the spatial variability of soil conditions (or crop properties) is, the higher the potential for precision management and the greater its potential value. The difficulty of assessing variability, however, increases as the dynamics of the temporal component increase.

The application of WSN to agriculture has been described in many studies. Most often it is applied to precision viticulture (Diaz et al., 2011; Matese et al., 2009; Morais et al., 2008; Peres et al., 2011), where the demand for environmental information is greater because of the higher intensity of crop management (crop fertilization, crop protection, and irrigation). The scale and structure of a monitoring network in a vineyard is determined by the heterogeneity of the terrain and by soil conditions. The next typical deployment of WSN in agriculture is in the area of crop irrigation management (McCarthy et al., 2010; Vellidis et al., 2008).

1.3. Integration of sensors and geospatial infrastructure – Sensor Web Enablement framework

Since 2002, the Open Geospatial Consortium (OGC) has managed an initiative called Sensor Web Enablement (SWE) focused on the construction of a framework of open standards for utilizing web-connected sensors and sensor systems of various types. The initial focus of OGC's SWE has been to investigate the use of standardized interfaces for live sensors operating in near-real-time, rather than conventional static data stores. It addresses information gathering from distributed, heterogeneous, and dynamic information sensors and sources of different types. These are based on web services.

Since 2007, OGC members have been working on the second version of SWE. Bröring et al. (2011) state that SWE 2.0 brings greater coherence to individual SWE specifications together with conceptual and formal clarity, rather than new features. The 2.0 version consists of the following features: the SWE Common Data Model, the SWE Service Model, the Sensor Observation Service, the Observations and Measurements feature, and the Sensor Planning Service. Observations and Measurements 2.0 is the first part of the SWE standards family that became an ISO standard (ISO 19156, 2010).

1.4. Visualization of sensor data

Visualization is important when working with sensor data. When properly selected, it makes working with the data more comfortable for the user, and the data can be understood more quickly and easily. With suitable visualization, it is possible to find patterns, connections or similarities in the observed agricultural data (see Dvorsky et al., 2010). This makes it much more convenient than the manual analysis of raw sensor data, which is sometimes impossible for a person to understand. Sensor taxonomy or the classification of the fields of applications where sensors are used (see White, 1987; Richter, 2009; Zerger et al., 2010; Horak et al., 2008 for examples) can help a developer when implementing visualization.

Sensor data usually exist as numerical values; therefore, the process of understanding or analysing them is not trivial. In many cases, finding patterns, differences, and commonalities is hardly possible without deeper analysis or visualization. Sensor observations are analysed, extracted, and aggregated, and the ensuing visualization of the results gives the user a graphical interface and representation. This representation makes it easier to understand the data and to interact with the data set (Richter, 2009). According to Plaisant (2004), the biggest problem when designing visualizations is fitting the visualization to the wishes of the user, to the task and to real world problems. In trying to display the data, different views of the same data set should be made available. The properties of the sensor data (qualitative, quantitative) have to be taken into account in order to obtain a good visualization of the sensor data. There is a dependency between the task and the visualization, so the task of the sensor is one starting point.

Erharuyi and Fairbairn (2003 and 2005) described the concept of the task-centered adaptation of geographic information delivery and emphasized, in particular, that individual pieces of information require optimization based on location, user, goals, and tasks, allowing for the determination of situation-adapted information solutions. The principles of adaptation deal with the identification of so-called "contexts" – see Stanek et al. (2010), Kubicek et al. (2011). The context is a set of determinants identifying particular cartographic representations – the user's profession, the type of device displaying the map etc. "From the cartographic point of view, context is closely related to the purpose of a map" (cit. Kozel and Stampach, 2010).

The process of map adaptation includes operations that change the map's properties, e.g., content, symbology, cartographic method, coordinate reference system, extent, and scale (Konecny et al. 2006). "Adaptation means above all highlighting the most relevant information along with suppressing the irrelevant" (cit. Kozel et al., 2010). If the context is changed, an appropriate visual representation must be selected.

We can distinguish the many attributes of map context and their impacts. The selection of these attributes is closely related to the overall purpose of map representation. After selecting the context "sugar beet sowing", the adaptive map shows only the fields dedicated to sugar beet and the sensors located in these fields. Other information that is not needed is filtered out. The colour of the symbol on the sensors measuring temperature can signal if the actual temperature is higher than 6 °C, which means that the temperature is conducive to the sowing of sugar beet.

2. Materials and methods

The Agrisensor project (Kubicek et al., 2009) followed the above-mentioned concepts and aimed to design and develop an integrated framework of cartographic visualization for agricultural applications based on wireless sensor networks information.

The suggested framework was based on the following components (see Fig. 1):

(1) A heterogeneous distributed network of hierarchical agricultural sensors.
(2) Communication infrastructure and standardized interfaces between sensors and the Internet.
(3) Web-enabled geoinformation infrastructure for effective visualization of sensor data.
(4) Cartographic visualization rules and modeling tools for effective support of agricultural decision-making.
(5) An agricultural knowledge base and data warehouse for sensor data storing.

The following sections describe the achievements of the Agrisensor project related to the aforementioned conceptual principles.

2.1. Monitoring methods

Testing of the wireless sensor network was carried out in 2010 and 2011 at the Field Experimental Station of Mendel University in Brno (locality Žabčice, Czech Republic; 49°1.37′N, 16°37′E). In the period 1961–1990, the standard annual temperature at the location was 9.2 °C and the annual precipitation was 483 mm. A small number (5–8) of sensor nodes were distributed over a small-plot field planted with different crop species (maize – *Zea mays* L., winter wheat – *Triticum aestivum* L., spring barley – *Hordeum vulgare* L., sugar beet – *Beta vulgaris* L.) and which utilized different soil tillage practices: traditional (CT, ploughing) and reduced (RT, shallow tillage).

The temporal dynamics of weather parameters, which are important for crop growth (soil and air temperature, soil moisture, air humidity) were monitored. Other important meteorological parameters such as precipitation, solar radiation, and wind speed and air flow direction were measured by a meteorological station installed in the centre of the experimental site. These meteorological parameters were considered constant over the field area.

A catalogue of available geospatial data, both from local and remote Web Map Services (WMSs), was developed for selected experimental fields. This set of geodata sources is intended for a general overview of the experimental plots within the visualization client. It also serves as a knowledge base for the visual exploration of the spatio-temporal dependencies between the measured sensor data and the environment. Local geographic data were measured and collected at a very detailed level and dealt with individual sensor locations, including the histories of particular crop locations and their alternative cultivations. Information about soil conditions to a depth of 0.75 m was obtained by on-the-go measurement of soil electrical conductivity, which enables rapid and non-

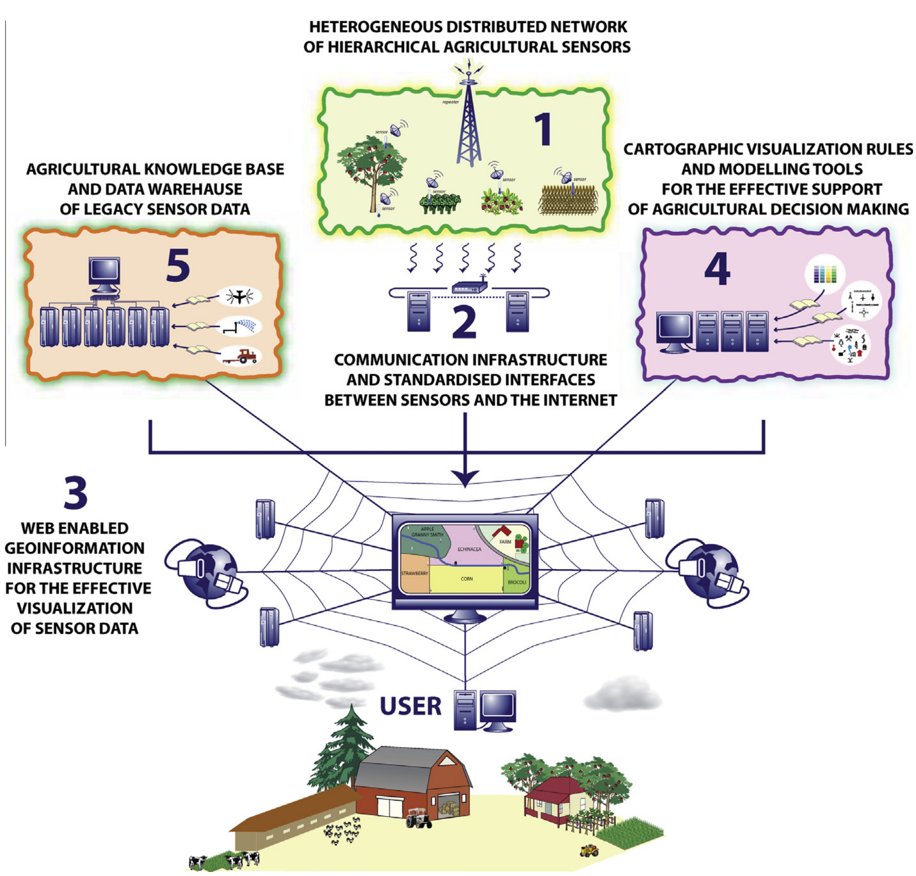

Fig. 1. Overall framework of Agrisensor project with main technological components.

invasive analysis of the soil substrate. The methodology and results of this survey were described by Lukas et al. (2009).

2.2. Data flow and database

The term "sensor" is used in the following section for a piece of equipment which measures one characteristic – for example, humidity or temperature. "Sensor unit" means a group of sensors placed in the same location. One sensor unit consists of different types of sensors. Therefore, a sensor unit measures several characteristics. In our project, each sensor unit was designed as a pole with sensors (Fig. 2).

Nowadays, there are many technologies available for building wireless sensor networks. They can be implemented on different platforms. Wi-fi and ZigBee are the most often used. However, their common drawback is that they are only able to guarantee communication between sensors at a distance of only tens of meters. A new communication platform called VLIT (Very Long range Identification Tag) was used for the building of the sensor network. The platform is characterized by an 868 MHz working frequency (RFID) and a protocol that supports communication both for short distances between nodes in modes Point-To-Point and Point-To-Multipoint and for longer distances, when a relay station gathers the data from nodes. The relay station also communicates with the Internet using GPRS.

The experimental wireless sensor network was composed of two hierarchical levels of hardware components:

- L1 – nodes: a series of peripheral wireless sensor units which communicate by means of the RFID protocol. Each sensor unit includes a master processor and digital input/output with sensors that measure temperature and humidity for both soil and air. Besides meteorological variables, technological information is also measured (signal strength, battery voltage) for better network maintenance. The following types of sensors were used:
  - a combined sensor for air temperature and air humidity based on a Sensirion SHT10 chip with the I2C communication interface;
  - a soil temperature sensor based on a Dallas DS18B20 chip with a 1-wire bus communication interface;
  - a VIRRIB LP_V soil humidity sensor.
- L2 – a relay station: a mobile communication unit based on an ARM processor and a GPRS (General Packet Radio Service) communication unit. This unit has a twofold function within the WSN – it is equipped with independent meteorological sensors (for data calibration) and also includes a radio module for communication with the L1 level nodes. The L2 node is responsible for data pre-processing.

Each sensor of the L1 component measures its phenomenon during a preconfigured time period, which is typically several seconds or minutes (in our project a 15 min period was used). When a new value is measured, it is instantly transferred to the L2 component by means of the local wireless network. The value is then automatically sent by the L2 component to the remote main server using the GPRS connection. The main server then inserts the data into the database. A detailed description of the VLIT can be found in Charvat et al. (2010).

The database structure follows the Observations and Measurements ISO 19156 (ISO 19156, 2010) UML (Unified Modeling Language) model (see Fig. 3). The OM_Observation represents an act of observing a property of some feature. The model is able to present information about the observation, which includes: the measured characteristic (e.g. temperature), the feature which has this characteristic (e.g. air), how it was measured (e.g. resistance thermometer), when it was measured (e.g. 2012-06-23 12:56), where it was measured (e.g. N49°1′18.9″ E16°36′56.4″), and the result (e.g. 25 °C).

When the measured data is stored in the central database, it is accessible to users by means of web service which is based in the Sensor Observation Service (SOS) specification. At the moment, this service used in our application is not fully SOS 2.0 compliant. However, it follows all the major principles and supports requests describing the sensor unit, requests describing the sensors and observed phenomena, and requests for obtaining measured values. The web service transmits the measured data from the database to the client side in the JSON format (JavaScript Object Notation).

Fig. 2. Sensor unit L1 installed in a small-plot field of maize at the Field Experiment Station of Mendel University in Brno. Sensor and detail of the L1 situated in spring barely, with a description of its functional parts.

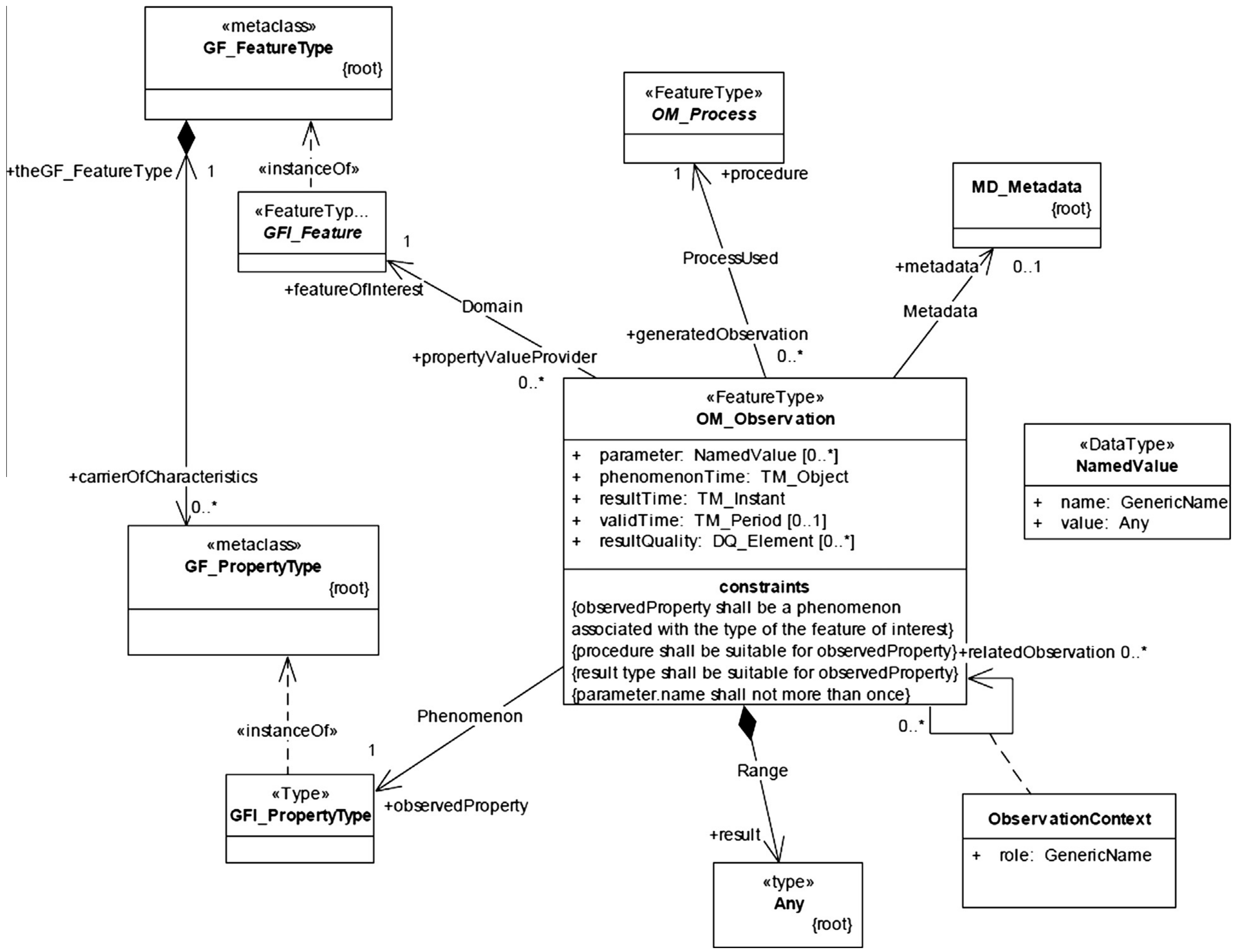

Fig. 3. Part of the ISO 19156 Observations and Measurements UML model, upon which the project database structure is based (from ISO 19156, 2010).

This format can then be easily used for the AJAX (Asynchronous JavaScript and XML) client application and near-real-time visualization.

3. Results and discussion

Achieved results were analysed from the following standpoints: (1) from the standpoint of agrometeorological measurements; (2) from a wireless sensor network testing standpoint; and (3) from an adaptive visualization deployment standpoint. Each of these aspects is described below and discussed in the context of similar studies.

3.1. Agrometeorological measurements

The results from our testing of WSN show that the deployment of nodes across fields with different crops provides more detailed information about the microclimate of the crop stand and soil conditions. This allows for adaptation of the crop management approach for specific crop/field environmental conditions in conjunction with the regional agro-meteorological monitoring of a self-acting meteorological station. Fig. 4 shows in detail the differences in soil temperature between conventional tillage (CT) of maize and the no-tillage (NT) variant during an 8-day period in July/August 2011. The range between minimum and maximum temperature values for conventional tillage was higher than that for the no-tillage variant, which corresponds to the soil temperature regime of both variants in the upper soil layer.

Similarly to the case with soil temperature, agrometeorological monitoring using WSN manifested differences in soil moisture

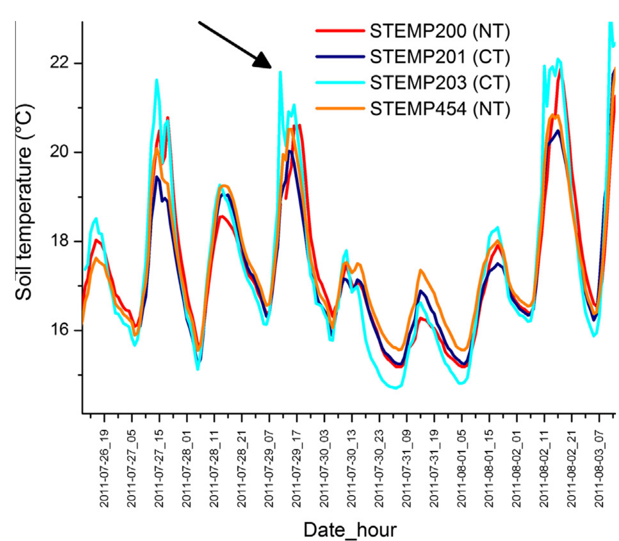

Fig. 4. Graph of soil temperature (at a depth of 5 cm) measured during the vegetation of maize over an 8-day period in July/August 2011. The arrow shows the differences in values between conventional tillage (CT) and no-tillage (NT).

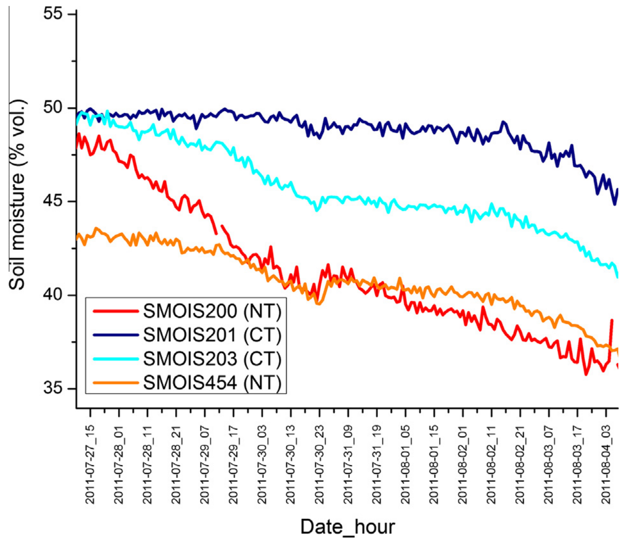

Fig. 5. Graph of soil moisture under different soil tillage regimes (CT – conventional tillage, NT – no-tillage) for maize during a 9-day period in July/August 2011.

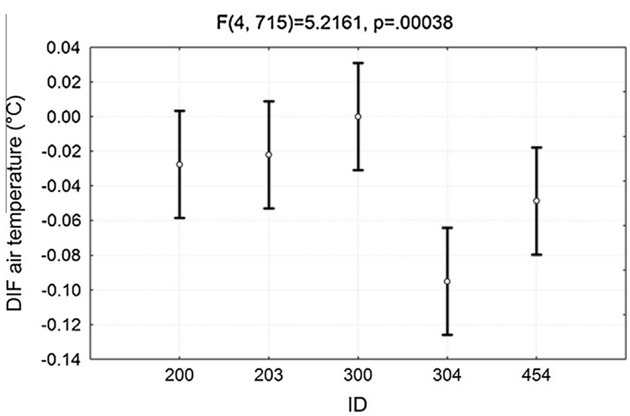

Fig. 6. An ANOVA evaluation of differences among air temperature sensors (TH2E) during September 2011 (compared to sensor ID 300). The nodes were placed out of experimental plots to guarantee the same measurement conditions for all of them.

during the maize vegetation period for both mentioned soil tillage variants. Fig. 5 shows decreasing soil moisture from the end of July to the beginning of August 2011. Higher values of volumetric soil moisture were observed for the conventional tillage of soil, represented by ploughing, while the no-tillage variant with direct seeding showed lower values and thus a faster decrease in soil moisture.

The quality assessment of air temperature measurement among the sensors of different node units was performed in September 2011. All sensor units were relocated to one experimental plot with no agricultural activity. The values from all sensor units were compared to the values from unit ID 300 and the differences were statistically evaluated by analysis of variance. The ANOVA showed significant deviation for sensor ID 304 (Fig. 6), which provided the lowest values of air temperature. Nevertheless, the absolute differences were smaller than the thermal sensitivity (0.1 °C) and accuracy (0.5 °C in range 0–40 °C) of the tested sensor.

The described testing of WSN on arable land indicated some drawbacks connected to the following of crop management treatments and crop rotation. The most problematic was the manipulation of the soil moisture sensor (VIRRIB, AMET Czech Republic, described in Litschmann, 1991), which was buried in a vertical position to cover changes in volumetric water content from 0 to 30 cm. The soil moisture sensor was originally connected to the other sensors on a particular node (sensor unit) via a cable. However, the soil moisture sensor had to be removed from the soil before soil cultivation (soil tillage or sowing). Continuity of measurement was thus not assured. Moreover, the VIRRIB soil moisture sensor had to be covered by wet soil (mud) during reinstallation. This artificial moistening influenced the measurement of soil moisture values.

Discontinuities in soil moisture measurements and the influence of artificial moisture limit the use of field-specific agrometeorological monitoring in conditions in which the soil is heterogeneous at the farm scale. However, the network observation of meteorological phenomena can help to improve agronomical decisions regarding specific land units. It can, for example, serve as the spatially-defined input information for drought prediction (Mozny et al., 2012) or to refine the input parameters of crop and soil models, as shown in the case of the Hermes model by Hlavinka et al. (2013).

3.2. Wireless sensor network testing

The VLIT communication platform was examined in a two-step process. Both units (L1 and L2) were first tested inside a climatic chamber in order to check the functionality in severe climatic conditions. The composite temperature/humidity cyclic test (EN 60068-2-38:2009) and the damp heat, cyclic test (EN 60068-2-30) were used for performance verification. Both measured variables and data transfer were observed via the web application. Wireless sensors as well as the communication unit successfully passed both tests. For a detailed description of VLIT technology see Charvat et al. (2010).

The VLIT platform's technological principles were used for the field prototype in the second step. We faced a problem with (L1) node construction in the maize field. Since the height of maize changes during the growing season, it was necessary to develop an extendable pole assuring wireless transmitter visibility above the average crop level. The original cable connection between sensors was also changed and fully wireless communication was used at the sensor unit level. Other problems were connected with sensor malfunction in freezing temperatures (i.e. temperatures below 0 °C). These problems were overcome by means of a firmware upgrade, which assured full functionality during potential winter season measurement.

The main features and advantages of VLIT can be summarised as follows:

- A bi-directional communication protocol.
- A communication distance of 200–800 m (depending on the environment, weather, and location of sensors).
- Different communication modes: challenge, selective call, communications event management.
- Very low power consumption.
- A lifetime of 6 months – 5 years (depending on battery size and type of communication).
- The ability to connect to existing mobile solutions that ensure the collection of measurements and their transmission to the Internet environment.
- An integration into the Web environment, storing data in standardized formats.

The application of WSN to the concept of precision agriculture assumes monitoring within fields for site-specific crop management. In addition to its use for site specific crop protection and irrigation, it provides the potential for the variable rate application of nitrogen fertilizers on fields with higher heterogeneity and topography. Information about soil moisture obtained from WSN can be used as another data source to determine fertilizer doses. For example, the spring application of nitrogen fertilizers to winter cereals can be limited on sites with dryer conditions, where the nutrient is not utilized because of a lack of water. Camilli et al. (2007) and Spiliopoulos et al. (2011) describe the evaluation of spatial data from WSN using spatial interpolation techniques.

3.3. Adaptive visualization implementation

For exploring and visualizing measured sensor data, an interactive web client was developed implementing the basic principles described above. Namely, the concepts of adaptive visualization were followed. The client has two main views: map view and chart view (Figs. 7 and 8).

The map enables hierarchical, predefined views, from a general overview of the entire studied area, through particular agricultural experimental plots, to a detailed view of sensor locations.

In the most detailed view, sensor units are displayed. They are represented by multivariate symbols in which the latest measured values appear. By clicking on a sensor unit symbol, it is possible to see the values of this unit in a chart view.

In the chart view, an interactive chart is drawn based on the sensor and time range selected by the user. It is possible to choose one or all of the sensors measuring the same phenomenon so that differences between the measurement sites can be seen. Underneath the chart, the user can view statistical information about the currently displayed dataset. The user can use the mouse to choose one section of the time axis and to zoom to more detailed time units (e.g. from months to days). This means that the chart can be used to search for measured values or their trends over the whole period as well as for one exact value at an exact time. Drawing the chart for a whole year from values measured every 15 min would be time consuming. Therefore, the client is able to choose the level of aggregation – hour, day, week, or month. In this case, only the mean values are transferred from the database (e.g. monthly or daily means). This solution allows for very fast redrawing of the chart and a rapid time response to user demands.

The aforementioned principles of adaptive cartographic visualization were applied to three different levels – map view, dynamic cartographic symbology, and the dynamic measurement chart. Agricultural contexts are intended to provide visual support for decision-making, in particular with respect to agrotechnical activities. Each context is a combination of two parameters – Crop and Activity. The Crop parameter sets out the spatial and temporal extent of available plots for relevant crop types (maize, barley, sugar beet, wheat), while the Activity parameter indicates the agrotechnical operation (sowing, harvesting, tillage, fertilization). The particular context is then defined by the Crop + Activity combination (e.g. wheat + sowing in Fig. 9) and by a set of appropriate agrometeorological parameters measured by the sensors (the air temperature interval is indicated by a different coloured background in Fig. 9). The selection of a particular crop also influences the selection of the sensors. Only sensors within the crop-relevant fields are further visualized and visible.

Our system can be compared with a similar solution described in Riquelme et al. (2009). Both systems are based on a network of sensors that measure (among other parameters) soil humidity and temperature, provide wireless data transfer to a database, and offer data monitoring in an interactive web application using Google Maps.

The main difference is in the use of the possibilities offered by cartography. The solution devised by Riquelme et al. (2009) uses a map only for showing the locations of sensors, which are represented by simple point symbols. Measured values including the most current are visualised in tables presented next to the map. Historical data for a particular time period can be visualised or filtered after date selection using an interactive form.

Our solution exploits the map and chart maximally and in a way which is as user friendly as possible. All measured values and agronomical context-dependent values are visualised in the map directly at the location of the sensor. This allows the user to see the relationship between the measured value, the context limits, and the sensor location. The chart with historical data can be visualised after a simple click on the multivariate map symbol of the sensor. Data filtering and time period selection can be performed easily in the chart view with the use of a mouse.

As stated by Kozel et al. (2011), our client also brings one enhancement to the SOS service specification: it provides the ability to publish not only raw data (observed values), but also average values (i.e. day average, week average, month average, etc.). The week average is used in Figs. 8 and 9. This feature is very important for practical reasons. For example, in the case of a sensor measuring temperature once a minute, drawing a temperature chart for a period of one year would mean the necessity of transferring 525,600 values. However, by using the feature for calculating averages, the chart can be drawn from daily averages, which

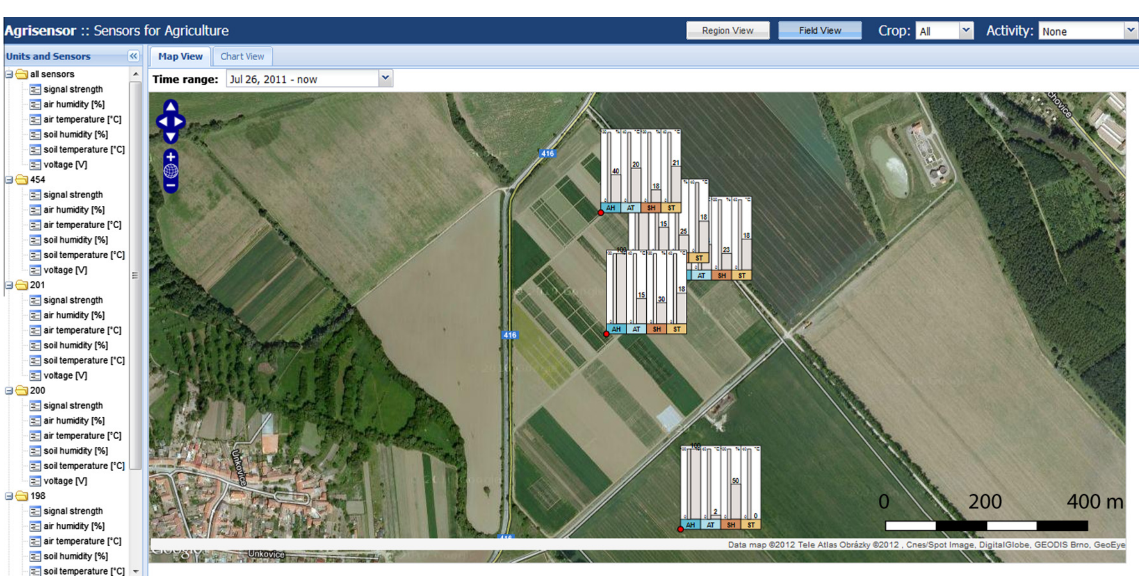

Fig. 7. Map view showing an experimental field with locations of all sensor units.

Fig. 8. Chart view presenting values from sensor No. 454 measuring air temperature from November 2010 to June 2011.

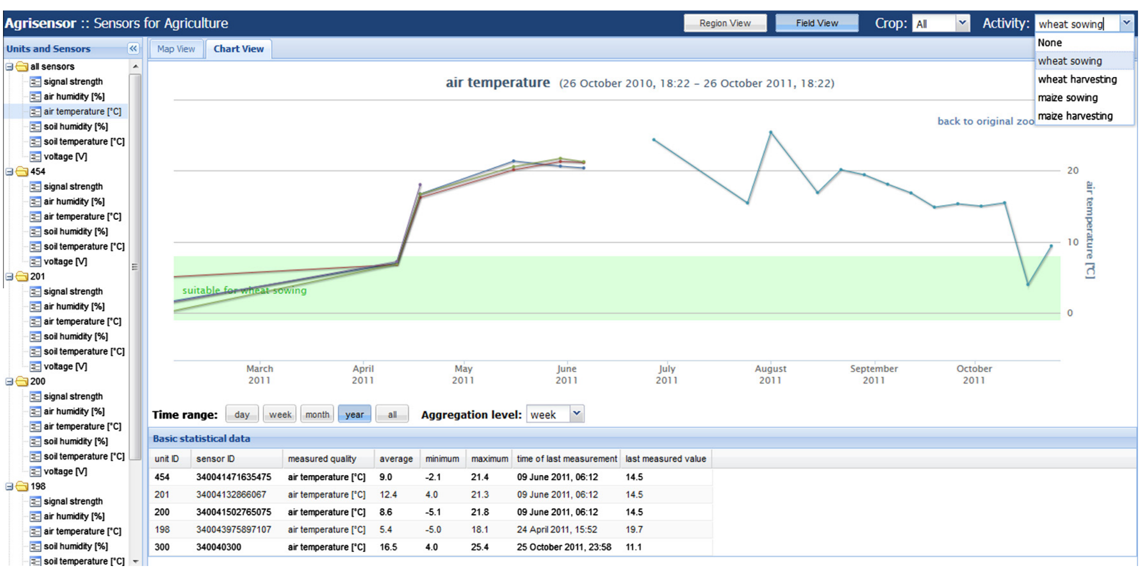

Fig. 9. Chart view presenting values from all sensors that measured air temperature in the time period March–October 2011. The range of values suitable for the selected context (wheat sowing) is indicated by a different coloured background. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

means the transference of only 365 values. We save not only bandwidth by using this approach, but also time, because encoding and decoding half a million observations is a time consuming process.

Adaptive visualization allows user to read and understand the data more quickly and easily. The overall effect on users is closely connected with the method of cartographic adaptation (size, colour, texture, orientation and other visual variables of the symbol). This can be a potential limit of our system. We suggested and implemented cartographic visualizations along with the recommendations of the cartographic theory, but it was not tested with the real users. Effectiveness and efficiency of adaptive visualization can be tested with use of psychological methods and special software (Hegarty et al., 2010; Konecny et al., 2011). Such testing of symbology and cartographic visualization used in our client is one of planned extensions of project.

4. Conclusions

In this paper, wireless sensor network geovisualization is presented at two different levels – the theoretical level deals with the conceptual approach and presents the theoretical background to the use of wireless sensor networks in agriculture and sensor geovisualization issues. The empirical level focuses on the application stage and describes selected problems prototyped within the framework of the Agrisensor project.

A sensor network measuring air and soil temperature and air and soil humidity was established. Data from the sensor network was transferred to a client application that provides an interactive way of exploring real time sensor data from the field. The main focus was on so-called context aware or adaptive visualization. The principles of adaptive visualization were applied at three different levels – the map view, dynamic cartographic symbology, and the dynamic measurement chart. Specific agricultural activities for specific crops (wheat + sowing) were used for context definition. Further development of the visualization client is planned, focused on the interface. The whole system is designed as extendable – new types of sensors, methods of data transfer, and other features can be used in the future. Also, in the future, user issues and issues relating to the interactive map interface should be addressed (Çoltekin et al., 2009).

Testing of the Wireless sensor network under the conditions of arable land with different crops and crop management systems over a two-year period proved the robustness of measurement (the reliability of the power supply, the success of communication between nodes and gateway, high resistance to weather conditions). We also found it possible to detect differences in crop microclimate and soil condition.

The monitoring framework developed and verified in this experiment should allow use of the application to be extended to different plant production systems, such as horticulture or viticulture. The potential for the use of these technologies in orchards, vineyards and gardens is higher because of the more intensive levels of crop management found there and because of the higher demand for agrometeorological data.

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