Challenges of agricultural monitoring: integration of the Open Farm Management Information System into GEOSS and Digital Earth

T Řezník¹, M Kepka², K Charvát³, K Charvát Jr³, S Horáková³, V Lukas⁴

¹Masaryk University, Brno, Czech Republic
²University of West Bohemia, Plzeň, Czech Republic
³WIRELESSINFO, Litovel, Czech Republic
⁴Mendel University, Brno, Czech Republic

E-mail: tomas.reznik@sci.muni.cz

Abstract. From a global perspective, agriculture is the single largest user of freshwater resources, each country using an average of 70% of all its surface water supplies. An essential proportion of agricultural water is recycled back to surface water and/or groundwater. Agriculture and water pollution is therefore the subject of (inter)national legislation, such as the Clean Water Act in the United States of America, the European Water Framework Directive, and the Law of the People’s Republic of China on the Prevention and Control of Water Pollution. Regular monitoring by means of sensor networks is needed in order to provide evidence of water pollution in agriculture. This paper describes the benefits of, and open issues stemming from, regular sensor monitoring provided by an Open Farm Management Information System. Emphasis is placed on descriptions of the processes and functionalities available to users, the underlying open data model, and definitions of open and lightweight application programming interfaces for the efficient management of collected (spatial) data. The presented Open Farm Management Information System has already been successfully registered under Phase 8 of the Global Earth Observation System of Systems (GEOSS) Architecture Implementation Pilot in order to support the wide variety of demands that are primarily aimed at agriculture pollution monitoring. The final part of the paper deals with the integration of the Open Farm Management Information System into the Digital Earth framework.

1. Introduction

From a global perspective, agriculture is the single largest user of freshwater resources, each country using an average of 70% of all its surface water supplies. An essential proportion of agricultural water is recycled back to surface water and/or groundwater. Agriculture, and especially water, pollution is therefore the subject of (inter)national legislation, such as the Clean Water Act in the United States of America [16], the European Water Framework Directive [2], [3], [4], and the Law of the People’s Republic of China on the Prevention and Control of Water Pollution [8].

The agriculture sector is in a unique position due to its strategic importance around the world. It is crucial for both the citizens (consumers) and the economy (regional and global) which, ideally, should make the whole sector a network of interacting organisations. Rural areas are of particular importance with respect to the agri-food sector and should be specifically addressed within this scope. The different groups of stakeholders involved in agricultural activities have to manage many different and heterogeneous sources of information that need to be combined in order to make economically and environmentally sound decisions, which include (among others) the definition of policies (subsidies, standardization and regulation, national strategies for rural development, climate change), development of sustainable agriculture, crop recollection timing and pricing, plagues detection, etc.
In this context, future agriculture knowledge management systems have to support not only direct profitability of agriculture and environment protection, but also the activities of individuals and groups allowing effective collaboration among groups in agri-food industry, consumers, public administration and wider stakeholders communities, especially in the rural domain.

The European project called “Farm-Oriented Open Data in Europe” (FOODIE¹), funded between the years 2014 and 2017, addresses the above-mentioned issues. After presenting user needs and methodology in this paper, the results of the project in the sense of machinery sensor monitoring are discussed. At the end, benefits, opportunities and future development are mentioned.

2. User needs
The user requirements for future (precision) farming information systems have been collected for three pilots, where each pilot contains three use cases (scenarios). See [12] for further information. The pilots foreseen in the funded project phase are:

- **Pilot 1: Precision Viticulture (Spain)** focuses on appropriate management of the inherent variability of crops, an increase in economic benefits and a reduction of environmental impact.

- **Pilot 2: Open Data for Strategic and Tactical Planning (Czech Republic)** aims at improving future management of agricultural companies (farms) by introducing new tools and management methods, which follows the cost optimisation path and reduction of environmental burden, improving the energy balance while maintaining the production level.

- **Pilot 3: Technology allows integration of logistics via service providers and farm management including traceability (Germany)** focuses on integrating the German machinery cooperatives systems with existing farm management and logistic systems as well as developing and enlarging existing cooperation and business models with the different chain partners to create win-win situations for all with the help of IT solutions.

The user requirements matrix consisting of two hundred functional, information and non-functional requirements has been established for nine use cases. After having described the use cases in a semi-formal way using the template developed internally within the FOODIE project, formalisation was conducted through the UML (Unified Modelling Language) using activity diagrams for processes and class diagrams for data modelling in the way described by [10] and [11].

We may conclude that a farmer is in a difficult situation due to the amount of communication that (s)he needs to manage. As stated by [14], in terms of information handling the process is very labour-intensive and for most parts is performed manually. The important concerns and problems communicated by the farm managers include the time required for monitoring of field operations; difficulties in managing the finances and applications for subsidies, which is further complicated by the lack of integrated software and hardware; and the lack of coordination where such programs do exist. The farm managers have also expressed their need for additional information and advanced technologies to manage and monitor on-line data acquisition in the field. When looking at the external concerns, it is clear that this mostly refers to the need for sustainable production of farm products, which is further pursued by regulations, and the possibility of receiving subsidies when more sustainable management practices are abided by.

¹ See http://www.foodie-project.eu for further details.
Figure 1 illustrates the communication scheme between a farmer/farm manager and other stakeholders in the agricultural domain. Exchange of (geospatial) information on the environment likely represents one of the crucial data flows in the whole scheme. Among other things, a farmer/farm manager has to provide various information related to agriculture and pollution monitoring, such as:

- phosphates;
- nitrates;
- pesticides;
- (suspended) sediments;
- Faecal bacteria.

3. Methodology
Agriculture pollution is the subject of (inter)national legislation. Currently, the practices commonly used in the agricultural sector use methods and benefits of geospatial technologies as defined e.g. by [1], [5] and [9] only in part. Typically, the amount of a certain substance in a certain place is indirectly...
computed from the amount of the substance in the source product, corrected by solvent quantity and divided equally around the whole acreage of a plot. The computed average erases spatial variations.

On the other hand, precision farming relies on geospatial methods that are available through the Farm Management Information System (FMIS) tool. Any FMIS may also be considered a kind of Geographic Information System (GIS) as it provides answers to two basic questions: what has happened and where. FMIS effectiveness from the geospatial point of view is limited chiefly by the lack of accurate data. Therefore, regular monitoring by means of sensor networks is needed in order to provide evidence of environmental/water pollution in agriculture.

It is a paradox situation since there are proprietary FMIS’ on one hand and request for open data/services to power proprietary FMIS’on the other hand. A way out may be found in a form of an Open Farm Management Information System (OpenFMIS). Such OpenFMIS uses both open and proprietary data. Open data are used as inputs into an OpenFMIS, where geospatial data are the best example; e.g. starting from satellite and aerial images through cadastre to zones forbidding usage of nitrogen. Proprietary data comprises typically sensitive economic information like turnover of a farm, consumption of fertilizers/pesticides/fuels, wages of employees etc. Proprietary data remain in the system, no matter whether it is an FMIS or OpenFMIS. The greatest difference between FMIS and OpenFMIS lies in the presence of open application programming interfaces that allow (mostly) consuming data and/or functionality offered by other open applications.

Moreover, world-wide concepts like the Digital Earth and Global Earth Observation System of Systems (GEOSS) are the ideal candidates for the integration of such agricultural pollution data around the world.

3.1. Data sources
It goes without saying that the most precise data will always be the data gained through observations and measurements performed directly on the farm. So far, this is partly true in the contemporary practices of the precision agriculture. Sensor networks for atmospheric and meteorological conditions such as aerial and ground thermometers, anemometers, hygrometers etc. are available to farms. On the contrary, information on application of treatments may often be of significantly lower quality. The best data source in this sense is the tractor and its application machine. Issues related to manual and aerial application of treatments are, however, beyond the scope of this paper.

3.2. Added-value functionality
As depicted in Figure 2, a tractor contains a monitoring unit that is the centralised point from which it is possible to configure which data will be collected and how. A monitoring unit is connected to a GPS receiver to obtain the position of the tractor over the whole course of an agricultural intervention. The pilot tests of the FOODIE project have also contained the RTK (Real Time Kinematics) corrections in order to achieve more precise position measurements. The position of the application machine is computed from the position of the tractor and the size of the application machine. Communication between the tractor and the application machine is achieved through the RFID (Radio Frequency Identification). The RFID interface enables to set the whole solution as a modular one. It is then easy to combine any tractor with any application machine as far as they follow the same standards. The same applies to the ECU CAN/BUS (Electronic Control Unit Controlled Area Network) interface as a mediator between the monitoring unit and the software of the tractor.

2 The GPS receiver has been used for the pilot tests as described in section 2. If required, any GNSS (Global Navigation Satellite System) receiver may be used to integrate other navigation systems, e.g. the Chinese Compass, the Russian Glonass and/or the European Galileo.
All data are stored in a PostgreSQL (open source) database in version 9.3.6 together with its spatial extension PostGIS in version 2.1.0. The database schema follows the ISO 19156 Observations and Measurements concept [6]. Furthermore, the developed database schema was replicated in the Cloud (Infrastructure as a Service) provided by the Poznań Supercomputing and Networking Center (in Poland) using OpenStack as an Open Source Cloud Computing Software.

To summarize, the whole solution consists in a set of hardware (e.g. the monitoring unit, GPS receiver) and software (e.g. ECU CAN/BUS and RFID interfaces as well as the user application), designated as MapLogAgri. The MapLogiAgri may be understood as a hardware and software solution offering data for an OpenFMIS. The FOODIE system as a whole is then an example of an OpenFMIS.

4. Results

The aim of this paper is to prove the feasibility of an open and standardized near real time environmental monitoring on the level of the tractor and the application machine. Such monitoring has been proven many times in the past for proprietary FMIS’. The innovation lies in the verification of a standardized communication to OpenFMIS, i.e. a possibility to connect any tractor and/or any application machine to an OpenFMIS to achieve “plug and play” solution. This paper also provides the basis for advocating the integration with other data layers to address environmental, economic, and geospatial issues/benefits.

4.1. Environmental results

It has been proven that it is feasible to monitor the application of a certain substance including the spatial extent of such application. Verification on the “Tršice” farm (1’291 ha) in the Czech Republic has so far been performed for the phosphates, nitrogen and pesticides. It was possible to obtain a point cloud that may be easily grouped into the tractor/application machine trajectories. Information on the amount of the specific substance applied is available for each such point as well. A user of the FOODIE system may thus easily see whether a substance has been applied correctly and whether there was any change in the plan. A typical example of the latter may be a wrong application of pesticide due to strong winds and the resulting movement of the arm of the application machine.

Any available information may be used for the environmental burden reporting as required by the legislation in most developed countries.
4.2. Economic results
Even though economic results are usually the primary concern of a farmer, we may identify the economic benefits as a consequence of environmentally-conscious (precision) farming. Economic results have been identified in the following areas:

- data flows are automated, which leads to a decrease of the person’s effort on processing the information on the environmental burden;
- automatic preparation of the reference materials for subsidies;
- product application is more precise due to the advanced geospatial methods;
- information on fuel consumption within each place allows the farmer/farm manager to decide which tractor and application machine is the most efficient as well as to optimise the trajectory, e.g. with regard to the steepness and/or soil graininess; see [13] for more information.

4.3. Geospatial results
We may also identify geospatial results as a secondary benefit, supplementing the economic results. The pilots of the FOODIE project have verified whether or not it is feasible to compute a plot geometry from the machinery sensor measurements. This has been successfully demonstrated. Therefore, we may conclude that it is possible to use the described measurements as a source of geospatial information. If the farmer agrees to publish his/her geospatial data, it becomes possible to update the existing data sources, which are usually less precise for rural areas. Subtraction of unpaved roads has also been verified successfully. In conclusion, machinery sensor monitoring can serve as another source of VGI (Volunteer Geographic Information). See figure 3 for an overview of environmental (bottom right: phosphorus inserted into the ground), economic (top right: fuel consumption) and geospatial (top left: trajectories) results that are visualised according to the rules defined in [15] and [7].

Figure 3: Environmental, economic and geospatial results of the machinery sensor monitoring.
Standardised communication exists also on the level of machinery sensor monitoring. ISO BUS and ECU/CAN BUS, respectively, are used for communication on the sensor level. Note that the latest versions of ISO BUS do not offer as straightforward open communication as their predecessors did. It is an open question whether this is a consequence of a changing policy on the part of agricultural machines producers. Some of them recently introduced a new business model where the farmer only rents agricultural machines. The license agreement prohibits the farmer from buying the machine. As a result, all the data measured remain a property of the agricultural machine producer. We have identified this change as a threat to the openness of machinery sensor monitoring.

5. Conclusions

Machinery sensor monitoring represents a promising future development of the geospatial applications in the domain of (precision) farming. It is an example of ecological and economic synergies. World-wide integration platforms play a crucial role in this process, where the Digital Earth and the GEOSS are considered the ideal candidates. The FOODIE system thus acts as a mediator between sensor measurements on the one hand and the Digital Earth/GEOSS on the other hand. The presented Open Farm Management Information System (FOODIE) has already been successfully registered under Phase 8 of the GEOSS Architecture Implementation Pilot in order to support the wide variety of demands that are primarily aimed at agriculture pollution monitoring.

The FOODIE platform offers to the Digital Earth/GEOSS raw as well as processed data through open and proprietary Application Programming Interfaces (APIs). Lightweight APIs provide responses in a very short time; however, it comes at a price of interoperability. On the contrary, the available open APIs are standardised by the International Organization for Standardization, World Wide Web Consortium and/or Open Geospatial Consortium.

In total, 9 tractors and 23 application machines were monitored second by second within one year (March 2015 to February 2016) on the “Tršice” farm in the Czech Republic. Such monitoring has proven the need for robust cloud-based geospatial solution since ten megabytes of data were generated a day when operating on a real commercial farm with almost 1’300 hectares. Geospatial data discovered significant differences between economic (e.g. fuel consumption or time needed to perform the same operation) and ecological characteristics (e.g. number of applied fertilizers or pesticides as a result of an inappropriate trajectory). The discovered differences are a subject of ongoing analyses.

Another open issue lies in the area that affects Big Data in all its forms. Farmers in particular commonly distrust the companies aggregating data. Farmers are afraid that their sensitive data may be misused. Future efforts should, therefore, focus on the technological as well as the personal level in order to ensure that the MapLog Agrí application as well as the FOODIE system remains useful in daily life. In other words, the geospatial technology is ready to help minimise the environmental burden while maximising the economic benefits; the main obstacles now consist in insufficient policies and people.

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