Procedures and Benefits of an Integrated Soil Mapping System for Directed Soil Sampling

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Abstract

There is an increasing need for the development of information systems that can optimize field management by leveraging the information obtained from the huge volume of data related to spatial variation within agricultural fields. To that end, an integrated soil mapping system for directed soil sampling is presented in this paper. The system architecture is analysed, highlighting the interactions between the individual subsystems toward capturing their internal structure. The final product constitutes a useful and effective tool for supporting field management as a result of in-depth study using state-of-the-art sensors, data fusion and decision-making algorithms. The benefits of using such a system are multifold including: (a) Optimization of the application of inputs on the farm; b) Reduction of the environmental footprint of agricultural practices; c) Increase of the economic benefit from the cultivation.

Keywords

Precision agriculture, variable rate application, soil information management system, subsystems interconnection

1. Introduction

Given the triple challenges that should be addressed by agriculture, namely feeding a steadily growing world population, ensuring a livelihood for agrarian society, and preserving the natural environment, farmers are increasingly relying on precision agriculture. Precision agriculture refers, among other, to the possibility of varying application rates leading to more efficient use of inputs in accordance with the actual crop demands. In particular, variable rate application is of critical significance, as application of inputs, including seeds, water, fertilizers, and pesticides, takes place with reference to data gathered by sensors. In this context, the development of management zone maps is critical in order to guarantee high efficiency. For that purpose, the acquisition of data related to spatial variation within the field is essential [1,2]. However, of greater importance is how to exploit this information in the application of variable rate inputs and, in addition, how to manage these inputs in the most cost-effective way. As a consequence, reliable and user-friendly information systems that can tackle all these issues are required as a means of providing a technology delivery mechanism, the scarcity of which has long been recognized as a major barrier for precision agriculture to be widely adopted [3,4]. Furthermore, recent research has shown that the implementation of variable rate technologies appears to be very heterogeneous, with low adoption in small-scale farms and wide uptake in large-scale farming systems [5]. In this work, a Soil Information Management System (SIMS) is

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presented that aspires to demonstrate the benefits for small, medium and large-scale farming systems. The system architecture with the interconnection of the subsystems, the procedures and the benefits are discussed.

2. SIMS at a Glance

In brief, SIMS provides individualized results for each field, based on soil parameters mapping. At the same time, it automatically performs data analysis and data fusion of all levels of information. As an intermediate product, maps for targeted soil sampling are exported for increased efficiency of the sampling process, by taking the minimum possible samples, which are as representative of the sampled field as possible. The information system relies on a modular structure for the purpose of ensuring adaptability and flexibility by also following a system-of-systems (SoS) approach. The latter approach favors the interconnection of individual sensing, decision-making and action subsystems into an integrated framework. Hence, it offers access to the users to implement the optimal agricultural practice in each case. SIMS consists of three main subsystems, namely the “Initial Data Acquisition”, the “Data Analysis & Decision Making”, and the “Targeted Sampling” subsystem.

The procedure begins with the in-field and remote data collection. The system automatically downloads satellite images form Copernicus (Sentinel 2 mission). Other layers of information include; (a) Landscape mapping using a high-precision geolocation device (RTK-GNSS) for the production of digital terrain models; (b) Creation of three-dimensional point cloud by utilizing photogrammetry from imagery acquired by unmanned aerial systems; (c) Mapping of soil electrical conductivity; (d) Mapping of soil pH, by using an electronic pH meter; and (e) Mapping of soil compaction, by using a digital penetrometer.

The second step includes the data fusion of all layers of information using Fuzzy Clustering algorithms and the generation of zones for directed soil sampling. Next, directed soil sampling is performed on the basis of the sampling zone maps. The action is supported by a dedicated application for Android devices, which navigates the producer in the field to the sampling points. The final step is the delineation of application management zones and the exporting of prescription maps for variable rate applications.

The system is anticipated to support fully automated operations by using robotic vehicles for agricultural applications. Therefore, a situation awareness study is also carried out for the autonomous navigation of robotic vehicles within the fields, similar to recent studies like [6], for fully automatization of the mapping of soil properties and for obtaining all levels of information to supply the SIMS with the necessary information.

In summary, the three main actors involved in conducting the measurements are the user, an Unmanned Aerial Vehicle (UAV) and an Unmanned Ground Vehicle (UGV). In particular:

- The users, through the use of the specially developed Android application (app), are guided across the field to selected sampling points. This app also enables them to record the measured parameters. Apart from the soil sampling, the user, may also be responsible for measuring soil pH and soil compaction using handheld digital pH meter and soil penetrometer respectively and import the values in SIMS system via the app.
- The UAV, following the flight plan received from the central information system, undertakes the appropriate mission for the specific field of interest. The results are then provided in geo-referenced data files to the “Data Analysis & Decision Making” subsystem to be processed and generate the orthomosaic and the 3D point cloud.
- The UGV, through the routing plan received from the central information system, undertakes to conduct soil compaction measurements. Moreover, a conductivity meter attached to the UGV maps the soil electrical conductivity providing an insight of the soil variability. Furthermore, the high precision RTK-GNSS installed on the UGV provides the ground-based measurements for exporting the digital terrain model.

3. Subsystems Interconnection

This section presents the architecture of SIMS information system analyzing the interactions between the individual subsystems. The system architecture was strategically designed tailored to the needs of digital agriculture contributing to efficient management of the agricultural practices. The flow of the information that is exchanged throughout the operation of SIMS, can be seen in Figure 1. In this graphical representation, an overview of the interactions that take place within each subsystem and between them is illustrated. Subsequently, the interactions of the three main actors involved in performing the measurements, i.e., the user, the UAV and the UGV, follows to understand the flow of information that take place. Dotted lines used in Figure 1 indicate the procedures that can be performed manually by humans, in the absence of a UGV. As a general observation, the information exchanged between the three main subsystems are bidirectional. The core of the system is the “Data Analysis & Decision Making” subsystem is where the data is processed and all layers of information are fused in order to analyse them and find the optimal solution. The other two subsystems feed the main subsystem with the appropriate information for the analysis, while the targeted sampling subsystem is also responsible for taking actions for the zone-based targeted sampling.

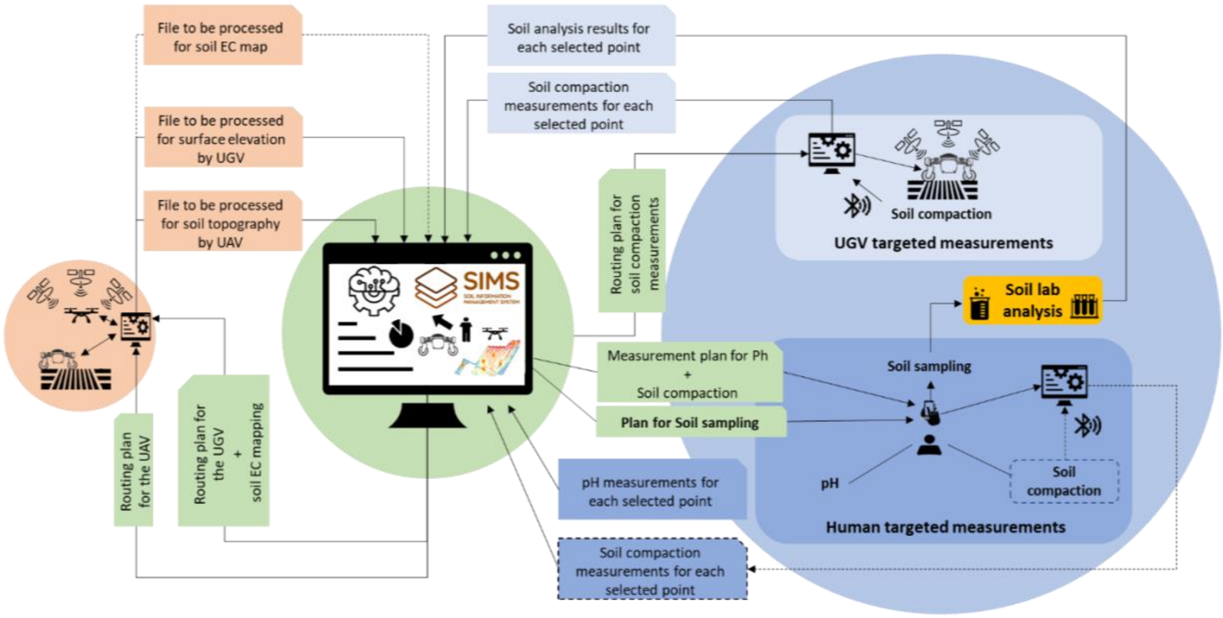

Figure 1: Graphical representation of the interactions that take place within each subsystem as well as between them; color correspondence with the subsystem: salmon represents "Initial Data Collection", green the "Data Analysis & Decision Making", and blue the "Targeted Sampling”.

3.1. Interactions of System Components Involving the User

As shown in Figure 2, the user interacts directly with the Android app to be guided to the selected sampling points and enter the measured values to the system. The Android app, in turn, interacts with the SIMS information system via the cloud service to send the measurements. The user undertakes only the manual measurements at the targeted locations exported by SIMS using the mapping data from the UAS and soil EC mapping. The manual, point measurements in the case study of this work, include the soil compaction using handheld penetrometer or the pH using handheld electronic Ph meter. After navigating to the measurement locations and acquiring the values, the information is sent to the central subsystem "Data Analysis & Decision Making" of SIMS for processing. The same protocol is also followed for the targeted soil sampling. The samples are sent for laboratory analysis and the results are entered in the platform as input for exporting recommendations.

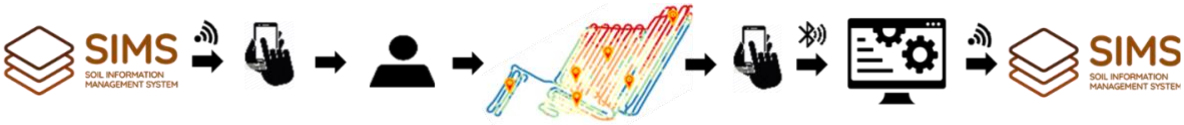

Figure 2: Interactions of system components and the workflow involving the user during the measurement at the targeted location in the field.

3.2. Interactions of System Components Involving the Unmanned Aerial Vehicle

The SIMS platform exports the flight plan that the UAV should follow in the field. The UAV equipped with accurate RTK-GNSS performs the flight, and takes a series of high-resolution aerial photographs with an appropriate degree of overlap between them. After the analysis, the detailed 3D point cloud of the field of interest is produced. This layer of information is them imported in the "Data Analysis & Decision Making" subsystem for processing.

Figure 3: Interactions of system components and the workflow involving the unmanned aerial vehicle.

3.3. Interactions of System Components Involving the Unmanned Ground Vehicle

The utilization of the UGV can be involved both at the initial data acquisition and at the targeted measurements field operations. It is a robotic platform that can support mounting of several agricultural sensors. In our use case the EM38 for mapping the soil ECa and the RTK-GNSS are utilized for the initial measurements of soil properties and landscape spatial variability. Through the "Initial Data Collection" subsystem the data are loaded in SIMS and the "Data Analysis & Decision Making" subsystem produces the zone map for targeted soil sampling and data acquisition. The UGV then receives the measurement locations and is guided autonomously in the field for the acquisition of the measurements. In accordance with the above, the UGV interacts directly with SIMS to receive the routing plan to follow during the measurements. In our use case, a customized mechanism is designed to mount the digital penetrometer on the UGV for the soil compaction measurements which are transferred to the controller via Bluetooth and to the SIMS platform via the cloud service.

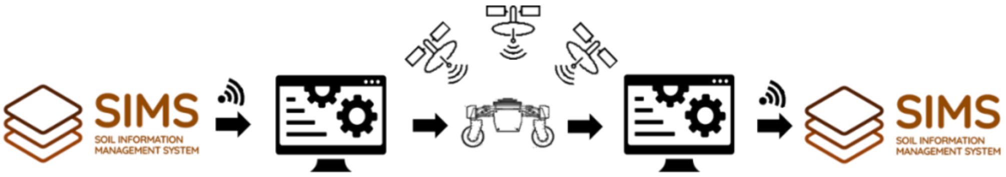

Figure 4: Interactions of system components and the workflow involving the unmanned ground vehicle for measurement of soil EC, soil surface elevation and soil compaction.

4. Conclusions

In summary, SIMS is an information system dedicated to soil management based on field variability measurements. It is developed following a system-of-systems (SoS) approach. In this paper the interactions occurring between the individual subsystems were briefly described with a view of comprehending the internal causal structure of the interconnections determining system behavior. The system is foreseen to provide a support tool for field management decision making (identifying problematic areas - hotspots, supporting implementation of agricultural applications in variable rates based on field variability, etc.). Consequently, the proposed field management is the result of a thorough investigation of all the parameters that are critical for the development of the crops. The aim is to make available to farmers and farm managers, digital agriculture technologies that may lead to yield maximization, increased application efficiency, reduced inputs and energy minimizing the environmental footprint of agricultural activities.

5. Acknowledgements

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