Integrated Soil Mapping System for Directed Soil Sampling

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Abstract

Soil properties vary spatially, thus, reducing the application efficiency of inputs like fertilizers and irrigation, in case they are uniformly applied. Consequently, there is a need to develop systems that can acquire information from in-field measurements and convert it into advice for appropriate site-specific management. Toward that direction, the concept of an integrated soil information management system is described in this paper. In particular, the proposed information system receives data associated with soil properties, processes the available information by fusing the data form various layers of information acquired in the field and produces zone maps that determine the locations for targeted soil sampling. The measurements concern the pH, electrical conductivity and compaction of soil and are conducted either by sensors attached to an unmanned ground vehicle or manually by a user through exploiting the developed Android mobile application to guide them in the field to the sampling points.

Keywords

Soil management, precision agriculture, integrated information system, site specific management

1. Introduction

Nowadays, there is a plethora of challenges placing pressure on agriculture, including demographics, climate change, and natural resources depletion. Toward addressing these challenges, it is urgently necessary to increase the overall degree of efficiency of the farming practices by simultaneously reducing their environmental burden. Precision agriculture is a fundamental ingredient of sustainable agricultural systems that uses effective management strategies which exploit state-of-the-art Information and Communication Technologies (ICT) [1]. It aims at customizing management for small regions based on field variability, instead of managing the whole field as a single unit. The accomplishment of the goals of precision agriculture strongly relies on applying accurate techniques for determining the in-field soil properties, as soil constitutes one of the most vital aspects of agricultural production with a dominant influence on crop growth, yield and quality [2]. The conventional approach of grid soil sampling may no longer regarded adequate, since it can be time consuming and labor intensive [3]. On the other hand, random sampling without taking into consideration the field variability may be insufficient. Managing fields as a whole, can result in production inequality, which in some parts of the field, may be as low as to lead the producer to financial losses. As a consequence, it is essential to determine and analyse the specific characteristics of the soil across the field. This can be the basis for the application of inputs in variable doses with the intention of maximizing the yield and economic benefit in each part of the field, while minimizing the environmental footprint.

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Taking into advantage the advancement of new sensing technologies for agricultural applications, field variability can be examined and managed accordingly by implementing the right treatment in the right time and place. Nevertheless, the use of these sensors remains limited mainly owing to the specialized knowledge which is necessary for both operation and analysis of the produced field data. Hence, one of the main barriers in adopting precision agriculture technologies is the lack of automated procedures for data analysis as well as for the fusion of the various layers of information received from the fields. In this paper, the concept of an integrated Soil Information Management System (SIMS) is presented, which receives soil properties and other information from a number of sensors, fuses the gathered data and produces zone maps in order to determine the locations for targeted soil sampling and for site specific management.

2. Infrastructure of SIMS

SIMS is based on a modular structure toward enabling adaptability and flexibility, while, by using open standards it facilitates interoperability and data sharing. The suggested system incorporates integrated information management in conformity with the system-of-systems (SoS) approach. The SoS approach favors the interconnection of individual subsystems for sensing, decision-making and action taking, into a single system providing to the producer all the required elements to apply the optimal agricultural treatments [4].

As illustrated in Figure 1, SIMS consists of three main subsystems:

- The "Initial Data Acquisition" subsystem;
- The "Data Analysis & Decision Making" subsystem;
- The "Targeted Sampling" subsystem.

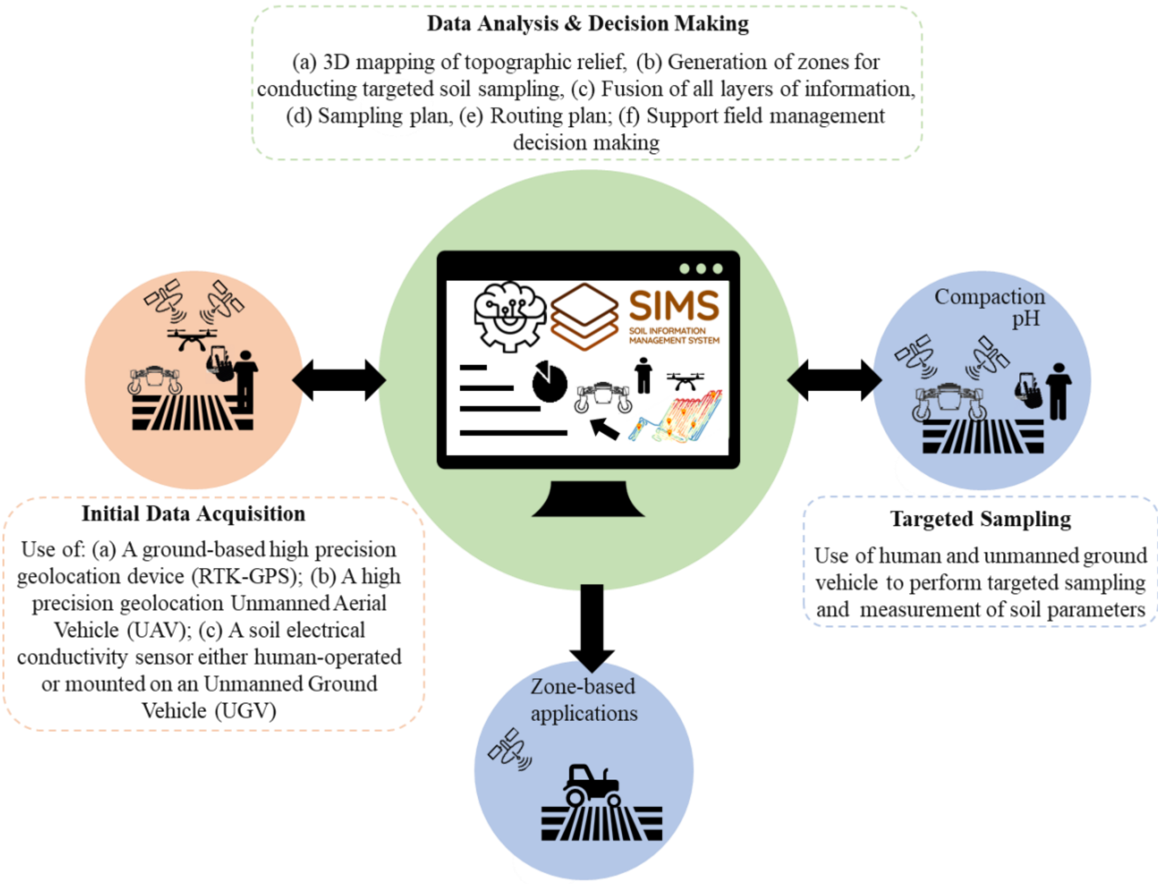

Figure 1: Graphical representation of the infrastructure of SIMS illustrating the three main subsystems and the basic elements contained in each of them as well as a summary of the implemented methodologies.

2.1. Initial Data Acquisition Subsystem

The objective of the first subsystem is the acquisition of the initial data for the delineation of sampling and management zones. The procedures include the mapping of field topography and soil electrical conductivity. The examination of these parameters is of major importance in agriculture, as they are related to soil properties affecting yield. In SIMS, soil mapping is made by utilizing high precision geolocation device (RTK-GNSS) to produce Digital Terrain Models (DTMs). Further, a three-dimensional (3D) point cloud is generated for 3D visualization of the topography and the various volumes and objects in the field, using photogrammetry from an RTK-equipped Unmanned Aerial Vehicle (UAV). Also, a soil conductivity mapping sensor is used to map the soil electrical conductivity at different depths. The system can either be attached to a UGV or manually operated by a human.

2.2. Data Analysis and Decision-Making Subsystem

This subsystem is the heart of SIMS. It interacts with both the “Data Acquisition” and “Targeted Sampling” subsystems and is responsible for data processing and fusion of all levels of information. In particular, th is subsystem initially receives the data from the soil EC and landscape mapping, performs the pre-processing and produces the 3D representation of the soil topography and the soil variability maps. With the utilization of Fuzzy clustering algorithms, it performs the fusion of the data layers and produces the zone maps based on which the soil sampling and measurement locations are defined (for soil pH and compaction in this study). In addition, this subsystem generates sampling plans and routing plans for the UGV. For manual sampling and measurement operations, the sampling plan is received by a specifically designed Android application (app), supported by a mobile phone or tablet that directs the farmer or worker in the field to the sampling points. In the same vein, the UGV requests and receives the routing plan from the central information subsystem.

The aim of these operations is to optimize the efficiency of the process by taking the minimum possible samples, which are as representative as possible. As shown in Figure 1, the data flow from the “Data Analysis and Decision Making” subsystem to the “Targeted Sampling” subsystem is bidirectional. This means that in addition to the aforementioned outputs, the "Data Analysis and Decision Making" subsystem receives as feedback the results at the targeted sampling/measurement locations (soil analysis results and pH and compaction measurements). Thus, the “Data Analysis and Decision Making” subsystem converts the above information into advice for enabling variable rate applications to manage within-field variability according to the needs of each location in the framework of applying the concept of precision agriculture [5,6].

2.3. Targeted Sampling Subsystem

This subsystem deals with the targeted measurements of soil properties, namely pH, and soil compaction (using soil penetrometer) and the targeted soil sampling. Parts of this subsystem may be fully automated utilizing UGV, or manual, human operated.

2.3.1. Unmanned Ground Vehicle (Case Study)

The robotic platform being used in the development of this system is Thorvald (SAGA robotics, Norway), which is a modular mobile agricultural robot both in terms of hardware and software [7]. In the context of the present system, the UGV is equipped with a ZED 2 depth camera (Stereolabs., San Francisco, CA, USA), a 3D laser scanner (Velodyne Lidar Inc., San Jose, CA, USA), an RTK-GPS (S850 GNSS Receiver, Stonex Inc., Concord, NH, USA) and Inertial Measurement Units (IMU) (UM7 IMU, RedShift Labs, Studfield, Victoria, Australia). The above equipment is used to provide information on the velocity, acceleration and position of the robotic system (with latitude and longitude coordinates) for optimal robot localization, navigation and obstacle avoidance. The UGV along with the implemented equipment is depicted in Figure 2a. The selection of the aforementioned sensors was based on their capability to be connected to the ROS (Robot Operating System) [8], which is an open source framework appropriate to robotic applications and is widely applied in various fields, including agriculture [9]. In brief, the robotic system receives a file from the "Data Analysis and Decision Making" subsystem with the routing plan. In order for the UGV to successfully maintain a safe distance and speed from potential obstacles, including humans, the open source package "ROS Navigation Stack" is used similar to previous studies [10]. A ROS node generates a time frame (tf) emitter from the robot for detected obstacles and, according to the tf values, a velocity controller keeps a safe distance. The measurements conducted by the robotic system in this case study are those of soil compaction using a digital penetrometer (FALKER, Porto Alegre, Brazil) (Figure 2b) in target locations, and soil ECa using the soil apparent electrical conductivity mapping sensor EM38-MK2 (Geonics Limited, Ontario, Canada) (Figure 2c). The corresponding sensors are fitted to the robotic vehicle to fully automate the measurements.

(a) (b) (c) (d)

Figure 2: The utilized (a) Unmanned ground vehicle, (b) Soil penetrometer, (c) Soil ECa mapping sensor, and (d) Portable electronic pH meter, toward facilitating the measurements.

2.3.2. Human

Part of the "Targeted Sampling" subsystem include manual human-based operations, who, via an Android app, installed on a mobile phone or tablet, can be guided in the field to the sampling points determined by the "Data Analysis and Decision Making" subsystem. The objective is twofold; a) to acquire the manually measured soil parameters such as pH directly from the given points and record the measurements to the app. The SIMS app retrieves information from the SIMS information system and, via using the Google Maps and the device's GNSS, can direct the user to the sampling points. Alternatively, it is possible to measure the electrical conductivity and soil compaction manually.

3. Conclusions

In conclusion, this work presents the concept of SIMS system as an integrated soil management system operating based on the principles of digital agriculture. The procedures for directed measurements of soil properties (pH, electrical conductivity and compaction) were also described in the present paper. The system consists of three main subsystems; (a) "Initial Data Collection", (b) "Data Analysis and Decision Making" and (c) "Targeted Sampling", which, in turn, are composed of individual subsystems. The objective of the system is to function as an integrated decision support tool to manage field variability aiming to maximize yield, by using state-of-the-art sensors as well as data fusion and decision support algorithms.

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