Computers and Electronics in Agriculture 154 (2018) 25–35

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Soil sampling with drones and augmented reality in precision agriculture

Janna Huuskonen, Timo Oksanen*

Department of Electrical Engineering and Automation, Aalto University, Finland

ARTICLE INFO

Keywords:
Soil analysis
Mixed reality
AR
Precision farming
RPAS

ABSTRACT

Soil sampling is an important tool to gather information for making proper decisions regarding the fertilization of fields. Depending on the national regulations, the minimum frequency may be once per five years and spatially every ten hectares. For precision farming purposes, this is not sufficient. In precision farming, the challenge is to collect the samples from such regions that are internally consistent while limiting the number of samples required. For this purpose, management zones are used to divide the field into smaller regions. This article presents a novel approach to automatically determine the locations for soil samples based on a soil map created from drone imaging after ploughing, and a wearable augmented reality technology to guide the user to the generated sample points. Finally, the article presents the results of a demonstration carried out in southern Finland.

1. Introduction

Today, most of the agricultural field work is carried out with human driven machines in broadacre farming. Because of intensive farming methods in mechanized agriculture, farmers lack hands-on experience with sensing the condition of the field.

Remote sensing methods have been proposed to help in precision farming to gather *data,* and with proper *analytics* the growth during the season can be monitored. More and more satellite imaging data is available during the season. For instance, satellite images from Sentinel-2 satellites are available and provided by European Space Agency (ESA) (Drusch et al., 2012).

Drones, or Unmanned Aerial Vehicles (UAV), or Remotely Piloted Aircraft System (RPAS) are another source for remote sensing. With drones, imaging is possible in cloudy conditions whereas satellite-based imaging is limited in these situations. However, operating with drones requires more effort both in pre-flight phase, flying and the post processing of images than satellite-based imaging. Nonetheless, with satellites, the resolution unit of images is in meters whereas drone imaging has a higher resolution in centimetre-level. (Matese et al., 2015; Bu et al., 2017)

Augmented Reality (AR) is the technology of superimposing virtual objects upon the real world (Azuma, 1997). The virtual content is not limited to visual objects as AR can be used on other senses as well (Azuma, 1997). The benefit of augmented reality is being able to give a user information that is unavailable to their senses and help them perform real-world tasks (Azuma, 1997). While augmented reality may be most familiar from entertainment games, such as Pokémon GO, the application areas of AR include medicine (Fuchs et al., 1998), tourism (Fritz et al., 2005), manufacturing (Caudell and Mizell, 1992) and robot teleoperation (Milgram and Ballantyne, 1997). Today, Augmented Reality equipment is available in the form of wearable glasses.

During recent years, research on using AR in agriculture has emerged. According to Cupiał (2011), AR has several potential application areas in agriculture and in the future, will be an essential tool in precision farming. Santana-Fernández et al. (2010) developed an assisted guidance system for tractors that uses augmented reality with wearable AR technology. As the tractor operates on the field, the parts of the field that have already been treated on are shown in the driver's view on augmented reality glasses (Santana-Fernández et al., 2010). Another navigation system for tractors was developed by Kaizu and Choi (2012) to enable night time farming. Research also suggests the use of AR in identifying pests (Nigam et al., 2011), plants (Katsaros and Keramopoulos, 2017) and weeds (Vidal and Vidal, 2010) and providing the user relevant information based on the identification. Moreover, de Castro Neto and Cardoso (2013) demonstrated the use of AR in a greenhouse. In addition, Liu et al. (2013) state that AR could be used to simulate the growth of crops and livestock, as well as visualize information and help a user to manage different agricultural tasks. Simulation was demonstrated in a study by Okayama and Miyawaki (2013), where an AR smart garden system was developed to teach precision farming concepts to beginners in farming. The system used wearable augmented reality glasses and instructions and plant growth simulations were shown in the user's view (Okayama and Miyawaki,

* Corresponding author at: P.O. Box 15500, Otaniementie 17, 02150 Espoo, Finland.
E-mail address: timo.oksanen@aalto.fi (T. Oksanen).

https://doi.org/10.1016/j.compag.2018.08.039
Received 2 February 2018; Received in revised form 16 June 2018; Accepted 30 August 2018

2013). Okayama and Miyawaki (2013) note that a head-mounted augmented reality device supports farming operations as the user is free to use their hands. Finally, in an application by King et al. (2005), information used for grape production was overlaid against a view of the physical world so that viticulturists could view this information on the grape fields.

In this article, we present a novel concept how to use a drone for soil map colour image acquisition and through automatic segmentation and sampling point selection, the augmented reality glasses guide the farmer to collect the samples representing management zones. For instance, in Finland, the Agri-Environmental Support Programme requires farmers to collect soil samples in a regulated resolution and frequency to receive subsidies (Agency for Rural Affairs Finland, 2018).

The objectives in this article are (a) to study a relevant application of augmented reality in agriculture in practice, (b) to find requirements for drone imaging to acquire valid data for soil mapping, (c) to study the chain of actions to create soil sample points automatically, and (d) to study specific user interface requirements for augmented reality view in the application of assisted soil sampling.

2. Motivation and process chain

2.1. Management zones

A soil map with measured properties is one of the most important data layers when preparing precision farming prescriptions. Even if online soil quality sensors have been developed to measure the soil properties on the fly (Mouazen et al., 2005), the common practice is to collect soil samples and the samples are analysed in a laboratory. For precision farming purposes, the field should be divided into management zones and locations for soil sampling should be selected properly to get information from the zones. Management zones that represent consistent conditions and are similar based on some quantitative measure (Zhang et al., 2002; Fridgen et al., 2004) can be derived from yield maps, satellite images or aerial images or some other measurements. Every soil sample is analysed in a laboratory and the analysis is charged per sample. For this reason, sampling and analysing every square meter of the field would be very expensive and cannot be justified for precision farming purposes. In precision farming, the management zones should be large enough so that the costs of soil sampling and laboratory analysis are lower or equal to the general benefits of precision agriculture, such as additional yield or better quality. In this article, each *management zone* is a uniform region in the field plot that is considered consistent in properties; thus, separated regions with similar properties are considered separate management zones in this article.

Aerial images representing the soil colour can be acquired every year after primary tillage operation. In no tillage farming, the soil is almost always covered by vegetation or crop residues and the colour of the soil cannot be acquired. However, occasionally a field in no tillage farming is ploughed to smooth the surface and after these rare operations, it is possible to acquire images to detect the soil colour.

2.2. Augmented reality

The purpose of augmented reality in this application is to aid the farmer to collect soil samples. The system should not hinder the performance of this task and should be intuitive to use. Moreover, the role of the application should be guiding the user and they should not be required to operate the software. Therefore, input from the real world to the application should be provided as automatically as possible. In addition, the guidance information should come to the user automatically without any need to search for it. Given these requirements, wearable augmented reality glasses are the obvious choice of hardware, as the virtual content will be in the user's view and they are free to operate their hands.

A sample representing a management zone contains several *sample points* that represent the zone. To collect soil from the correct locations, the location of each sample point should be represented to the user. Adding a visual mark to each sample GPS point can be used to illustrate the sites. The state of a sample point must be tracked and represented somehow, as the user must be able to differentiate between already collected and uncollected sample points so that soil is not collected from the same location twice. In addition to the sample point locations, information that supports the operation can be added, such as the amount of already collected samples. However, the user's view should not be cluttered with a multitude of visual cues. The environment should be visible so that the user can navigate the field safely. The information given by the application should be limited to only the relevant instructions and represented in a way that is easy to perceive. Colours can be used to enhance perception.

Augmented reality is not a common tool and is mostly known from entertainment games. While commercial wearable AR equipment today should be comfortable to wear, users may be reluctant to adopt the new technology (Azuma, 1997). To make the application more approachable and intuitive to use, it can be designed to resemble a game.

2.3. Summary of process chain

This article presents a complete working process to make soil maps by utilizing drone and augmented reality technologies. The process chain is presented in Fig. 1.

3. Drone imaging and segmentation

In some regions of the world, soil type varies in a single field plot and these variations are visible in RGB. Therefore, an RGB camera was used for aerial imaging with a drone. For aerial imaging a DJI Phantom 4 Pro (DJI, Shenzhen, Guangdong, China) was used with autopilot

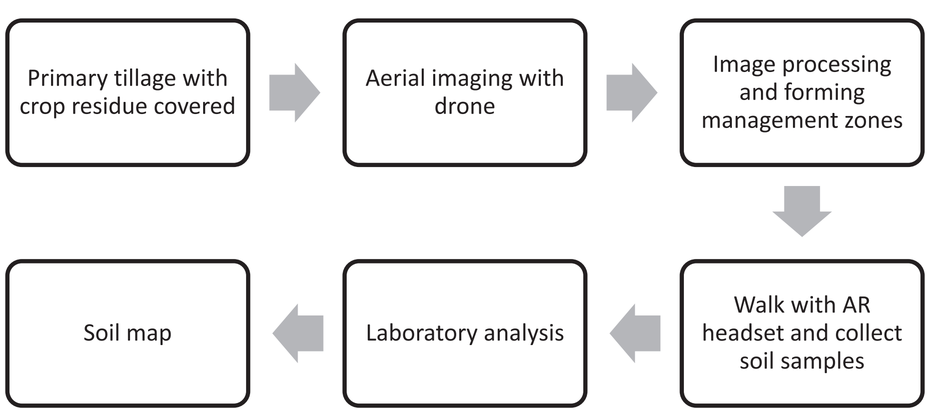

Fig. 1. The process chain presented in the article.