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Visual analytics and remote sensing imagery to support community-based research for precision agriculture in emerging areas

Mark P. Wachowiak[a,*], Daniel F. Walters[b], John M. Kovacs[b], Renata Wachowiak-Smolíková[a], April L. James[b]

[a] *Department of Computer Science and Mathematics, Nipissing University, 100 College Drive, North Bay, ON P1B 8L7, Canada*
[b] *Department of Geography, Nipissing University, 100 College Drive, North Bay, ON P1B 8L7, Canada*

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ABSTRACT

Agriculture in northern Ontario, Canada, has not yet reached the level of development of the southern regions of the province. In spite of the increasing desirability of the former region for agricultural expansion, northern agricultural producers – as well as other producers in "emerging" areas – have less access to information and decision support services relative to more established agricultural regions. At the same time, geographic information systems (GIS) are now being integrated into precision agriculture to assess field variability, to ensure optimal use of information, to maximize output, and to increase efficiency. To address this trend, a community-based research initiative based on an interactive web-based information visualization and GIS decision support system has been deployed with the aim of providing northern Ontario producers with access to the data they need to make the best possible decisions concerning their crops. This system employs citizen science and community-based participatory research to build a mutually beneficial partnership between agricultural producers, researchers, and other community stakeholders.

1. Introduction

1.1. Problem

Precision agriculture (PA) is "…the application of geospatial techniques and sensors (e.g., geographic information systems [GIS], remote sensing, GPS [global positioning system]) to identify variations in the field and to deal with them using alternative strategies" (Zhang and Kovacs, 2012), or "…a management strategy that uses information technologies to bring data from multiple sources to bear on decisions associated with crop production" (Li and Chung, 2015). PA has been adopted in both industrialized countries and in those where the average farm sizes are relatively small.

Agricultural producers that have knowledge of and are interested in inter-field variation are likely to adopt PA technologies (Zhang and Kovacs, 2012). Large tracts of land usually have spatial variations of soil types, moisture content, and nutrient availability, among other factors. PA relies on a variety of technologies, including sensor networks to collect soil (e.g. temperature, moisture) and atmospheric properties (e.g. precipitation, heat units), as well as imagery captured from satellites and, more recently, unmanned aerial systems (UAS). Remote sensing imagery is increasingly used to detect early signs of crop decay (Wilson et al., 2014; Li et al., 2016). Additionally, communications and information sharing mechanisms, and other technologies to acquire, process, distribute, and interpret vital data are needed for decision support. GIS is heavily employed in PA to determine field variability to ensure optimal use of inputs and to maximize farm output (Zhang and Kovacs, 2012). Therefore, with the use of remote sensing, GPS, and other types of imagery and time-series data, producers can more precisely determine what to plant and in what quantities, thereby assisting them in making more efficient use of expensive inputs, such as fertilizers and pesticides. Producers who practice PA methods do so to maximize crop yields, reduce operating expenses, and increase farm profits.

Because PA relies on complex, expensive technologies such as sensor networks, UAS imagery, and satellite imagery, as well as on digitized information available through government agencies (e.g. soil maps, drainage maps), producers are turning to other community partners. Community-based participatory research (CBPR) is defined as research undertaken as a partnership between community members, researchers, and other organizations (Israel et al., 1998). CBPR has been used successfully for applications in several areas, including environmental

* Corresponding author.
E-mail addresses: markw@nipissingu.ca (M.P. Wachowiak), danw@nipissingu.ca (D.F. Walters), johnmk@nipissingu.ca (J.M. Kovacs), renatas@nipissingu.ca (R. Wachowiak-Smolíková), aprilj@nipissingu.ca (A.L. James).

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monitoring (Wachowiak et al., 2015), in community-based environmental monitoring (Laird et al., 2012), and in agriculture (Arcury et al., 2001; Kerr et al., 2007). Citizen science is related to CBPR, and refers to obtaining research goals in part by distributing tasks to non-professionals (Hand, 2010).

CBPR is facilitated by various web services for sharing agricultural and environmental information, which have proliferated recently. A prime example is *CropScape*, an initiative of the U.S. National Agricultural Statistics Service (Han et al., 2012). *CropScape* is an interactive geospatial web-based system for disseminating, querying, visualizing, and analyzing crop and land cover classifications obtained from remote sensing data. The "Cropland Data Layer" is generated using information and satellite imagery provided by various federal government agencies. *CropScape* provides tools to analyze geospatial cropland information for agricultural decision support and research (Han et al., 2012). Since its inception in 2011, it has had over 81,000 users (reported as of 2013) (Mueller and Harris, 2013). In other examples, a web service is now exploiting the availability of global navigation satellite system reflectometry (GNSS-R) signals for assessing soil moisture (Du et al., 2016). Open geospatial web services can integrate heterogeneous information from multiple wireless and wired sensor networks for precision agriculture monitoring (Chen et al., 2015).

Visualization is a key component of web services intended to enhance precision agriculture. Tools such as GPS-based farming vehicles and other technologies create a massive amount of data that, because of their volume, are difficult to interpret. Producers therefore need data mining tools for understanding and interpreting their data. Visualization is the first part of the data mining process (Russ et al., 2009). For example, a recent study described a prototype system in which agricultural decision support is enhanced through cartographic visualizations, achieved by integrating current local environmental and agro-monitoring data with a GIS system (Kubicek et al., 2013). A web-based decision support system specifically designed for policymakers was introduced to assess the consequences of crop changes on multiple ecosystems (Tayyebi et al., 2016).

This paper focuses on a specific emerging agricultural region, northern Ontario, Canada, as a case study of how CBPR and citizen science can be employed to provide agricultural decision support services to these regions. At present, northern Ontario agricultural regions, which are relatively disconnected, sparse, and remote, have less access to information and decision support services relative to more expansive agricultural regions (e.g. in southern Ontario). However, there is a growing interest in the northern region (which includes a vast tract of fertile soil known as the "clay belt", comprising 180,000 km^2) due to lack of availability and cost of land for agricultural development in other parts of Ontario, and changing climactic and environmental conditions (Federation of Agriculture, 2016; Ministry of Municipal Affairs, 2011).

CBPR is one of the paradigms for agricultural data collection and dissemination in this region. Specifically, a web-based GIS service, called *GeoVisage*, was developed by Nipissing University (North Bay, Canada) to address the specific needs of the targeted agricultural producers (Research Matters, 2016). The service includes dissemination of both sensor data and imagery. The former includes real-time display of weather and soil data to visualize multiple sites and historical time-series, and a statistical display, while the latter includes many types of up-to-date imagery collected from satellites, UAS, yield monitoring, and digitization of soil, infiltration, and drainage information supplied by government agencies. The images are superimposed upon a topographical view of the region. Best practices in human–computer interaction makes the service intuitive and easy to use, especially for producers familiar with other GIS systems. Evidence that northeastern Ontario is a strategically important agricultural region includes increasing land values and the number of producers considering relocating to the region. New initiatives have been undertaken, including government-sponsored web services to assist new arrivals and those considering relocation (North Bay Nipissing News, 2016). The research described in this paper complements these efforts by providing GIS services to encourage precision agriculture and to provide decision support. Major stakeholders include agricultural producers, agricultural policy makers, and environmental researchers in several communities in northern Ontario.

1.2. Web-based interface

GeoVisage (http://geovisage.nipissingu.ca) is a web-based visualization, GIS, and decision support system resulting from a joint initiative between Nipissing University faculty and various agricultural producers, and is a component of several agricultural and environmental initiatives undertaken by the University (see, for example, Wilson et al., 2014; Wachowiak et al., 2015; Cable et al., 2014; Zhang et al., 2014, and the Integrative Watershed Research Centre: https://iwrc.nipissingu.ca). The goal of *GeoVisage* is to empower agricultural producers by providing decision support tools. Crop yields can be improved by providing participants with better information and tools to analyze that information.

The *GeoVisage* website contains multiple visualization tools. The Real-Time Data tool displays up-to-date graphs of sensor data from several weather stations. The Weather Station Data tool can be used to view all of the data collected by the network of weather and soil monitoring stations since 2009 to near-present, and can compare properties from different stations or time scales. It has a larger selection of features than the real-time data, but is updated less frequently. The Imagery tool is an interactive globe that can be overlaid with remote sensing images, soil maps, yield maps, and field imagery captured with UAS (i.e. Aeryon Scout, DraganFlyer X8, Aeryon Labs Inc., Waterloo, Canada).

1.3. Human computer interaction and community involvement

The *GeoVisage* interface was designed to be as intuitive as possible. Human-computer interaction design techniques, vitally important to the success of any geospatial service (Nittel et al., 2015), were employed. The services are presented as a broad interface that provides many options on one display. Interaction with imagery is based on standard paradigms featured in many GIS products. During its development, *GeoVisage* developers engaged with community users to ensure that the system met their needs. Users were specifically asked what data would be beneficial to them, and were also involved in defining the human–computer interaction requirements. After the initial deployment, the development team solicited feedback from producers to determine whether additional items would be useful.

As training in precision agriculture tools is beneficial to technology adoption (Seelan et al., 2003), instructional videos and tutorials are provided to assist users with the various system features. Groups of producers have also visited the developers for training. Demonstration of equipment and *GeoVisage* was presented at many local farm events, where additional feedback from producers was solicited.

Although *GeoVisage* is expected to be useful in addressing scientific questions posed by researchers and government agencies, the most important goal is to provide decision support to agricultural producers in northeastern Ontario. Therefore, a web-based visualization and imaging system was considered to be the best means of disseminating these data. Design requirements include (Munzner, 2014): presenting the data most relevant to producers, obtained through engagement and feedback throughout the development process; providing temporal and spatial comparisons; intuitive interaction; allowing several properties to be visualized simultaneously; providing interactivity in selecting time periods; facilitating discovery of both long and short term trends, patterns, and anomalies; regular data update; allowing multiple views of the same data; and calculating summary statistics.