A unified platform for GIS data management and analytics

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\section*{ABSTRACT}

In this work we propose a software platform for the collection, visualization, management and analysis of heterogeneous and multisource data for soil characteristics estimation. The platform is designed in such a way that it can easily handle proximity, airborne and spaceborne data and provides to the final user all the tools and proper visualizations to perform precision agriculture. The proposed software allows an easy integration of new data (that can be performed directly on-board of the acquisition device) and the possibility to add custom predictive systems for soil characteristic estimation. Usability experiments show that the platform is easy to use and effective.

1. Introduction

With the increase of population and the decrease of resources, sustainability is becoming an increasingly important issue and technological innovation can help to optimize all those processes that waste a lot of resources [1].

Agriculture is one of those sectors. In this context, the adoption of precision agriculture (PA) can dramatically contribute to improve sustainability [2]. Quoting the The International Society of Precision Agriculture\textsuperscript{1}, "PA is a management strategy that gathers, processes and analyzes temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production".

Data-driven Artificial Intelligence (AI) methods can help to support and/or automate management decisions [3]. Agricultural Decision Support Systems (DSS) have been created especially to support farmers in taking effective on-going and/or future decisions [3, 4].

DSS will guide effective agronomic practices to optimize the phases of mechanical processing, fertilization, weeding, irrigation, distribution of pesticides and harvesting to a very high degree of detail, by dosing the intensity according to the characteristics of the soil and the crop that have been measured and loaded into the system [5].

This significantly improves the entire process, thus reducing waste to a minimum and optimizing each intervention [6]. The use of data-driven technologies however require an expensive process of data collection and analysis. With the aim of avoiding mistakes, this process must follow strict acquisitions protocols and should be supported by an ad-hoc software platform [7, 8].

Furthermore, the scalability of the DSS on new areas (for which no samples are available) requires the use of AI-based predictive systems which are capable of performing an estimation of the soil characteristics from remote sensors [9]. Specifically, it is possible to perform soil characteristics estimation from airborne sensors such as drones or aerostatic balloons and/or spaceborn sensors such as satellites [10].

Data-driven AI methods require large amount of data to be stored, managed, annotated, visualized, explored, and eventually edited [11]. Most importantly, the DSSs should provide an intuitive and effective graphical interface to permit result interpretability for human supervision and understanding [12, 13].

In this work we propose the Pignoletto web-platform, which addresses all the aforementioned topics for supporting data-driven precision agriculture. In particular, the proposed platform:

- supports data collection and management from heterogeneous data sources
- provides all the tools for data visualization and decision-making
- provides soil characteristics AI-based predictors
- provides a procedure to include custom predictors

The platform has been populated with geophysical fields measurements acquired in the region of Lombardy (Italy) combined with airborne sensors (ionizing gamma radiation, optical hyperspectral, thermal multispectral), satellite information (PRISMA and Copernicus) and soil proximity measures. A great portion of the aforementioned data have been acquired within the Pignoletto Project \textsuperscript{2}.

The article is organized as follows: in section 2 we describe the technological context, in section 4 we describe in detail its architecture, in section 5 we present the hardware and software configurations used for the development of the application, in section 6 we present the results obtained through a survey on the usability of the platform and finally in section 7 we present our conclusions.

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\textsuperscript{1}https://www.springer.com/journal/11119

\textsuperscript{2}(more info here https://www.pignolettomibinfn.it/)

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2. Scientific and technological context

Geographic Information Systems (GIS) has emerged as an effective tool for the macro and micro level mapping of natural resources and artificial deployments, thus, their use extends to different sectors, from research to business [14]. There are several GIS software on the market but the most widely used are QGIS [15] and ArcGIS [16].

GIS are a powerful set of tools for collecting, storing and retrieving, transforming and visualizing spatial data. Their ability to analyze and visualize agricultural environments and workflows has proven to be beneficial for the agricultural sector [17].

GIS technology is becoming an essential tool for combining different sources of data, such as data acquired by drones, airborne sensors and satellites [18]. In the literature, GIS technology has been used in various scenarios. Frigerio et al. [19] proposed a methodology that exploits socio-economic factors to identify how different areas of the country can react to catastrophic natural events.

Blanco et al. [20], instead, exploited the potential of GIS systems to monitor the use and waste of plastic in the Puglia (Italy) region, in particular the tool developed allows stakeholders to quantify and localize areas characterized by intensive plastic production, thus allowing the study of the most suitable areas for collection centers.

Mancini et al. proposed a methodology for the management of landslide hazard [21], while Ladisa et al. proposed a methodology for the evaluation of desertification risks related to specific areas as in [22].

GIS tools are also playing an increasingly important role in precision agriculture, thus helping farmers to increase production, reduce costs and manage their land more efficiently [23, 24].

Furthermore, GIS have proven to be valuable tools in preventing soil erosion and degradation processes [25].

3. Pignoletto use case

In this context, the Pignoletto platform aims to target the specific agricultural needs of the Lombardy region which are the automatic creation of soil characteristics maps of the agricultural lands on basis of proximity, remote and hybrid chemical and spectral measures. The platform and its components are open-source tools and it leaves the possibility of being easily modifiable and adaptable for other locations or specific needs. This will support local farmers to adapt their practice in crop management.

The project considers two different types of land measures: 1) laboratory \( L \) measures and the drone acquisitions \( D \). The former set is collected in a controlled environment to support the training of a deep-learning-based system \( M \) able to estimate soil properties \( p \) from the spectral information \( h \), i.e. \( M(h) = p \). To this aim, each sample \( (h, p) \in L \) is composed by the hyperspectral signal \( h \) together with the soil properties \( p \) measured by an expert. The latter set is composed by drone acquisitions that will be loaded at test time. These acquisitions are acquired in the wild. Once they are loaded in the system, one or more predictive systems \( M \) will perform an estimation of the soil properties \( p \) associated to this signal.

4. Software architecture

The proposed platform, as also discussed in section 1, is designed to handle geophysical fields measurements acquired in the region of Lombardy (Italy) combined with airborne sensors (ionizing gamma radiation, optical hyperspectral, thermal multispectral), satellite information (PRISMA and Copernicus) and soil proximity measures.

Figure 1 shows all components of proposed Pignoletto platform and their interactions. The platform components can be grouped into server and client-side elements. The client-side is composed of several tools for interacting with data. The Map tool allows visual-based interaction with soil maps through a web browser; the Tabular tool allows the interaction with data in a tabular format; and the API (Application Programming Interface) tool allows the interaction with the platform through a computer program. The three interaction modalities are described more in detail respectively in subsections 4.1, 4.2 and 4.3.

The server-side is composed of a middle layer which orchestrates the interactions between the clients and the data layer. Specifically, for the Map component, the middle layer creates, at run time, a QGIS project and the corresponding Lizmap [26] configuration for the creation of the web interface. For the Tabular and API components, the middle layer exposes proper functions for data uploading, querying and editing. Data is stored in a PostgreSQL database with a CRUD-type storage engine (create, read, update and delete). Please refer to subsection 4.4 for further details.

The use of QGIS and its utilities allows the sharing of platform geographical data through Web Map Service (WMS) and Web Feature Service (WFS) which are well known standards in the GIS community [27].

All technologies used for the creation of the platform are free and open source. To make the system usable in any context and to maximize reproducibility, a Docker [28] environment containing all the necessary software and data samples was created. Here you can find the GitHub repository of the proposed platform.

The platform considers different types of users: 1) anonymous clients, 2) registered clients, 3) administrator. Anonymous users can only navigate the Map component without any possibilities to edit the content. Registered users can interact with all the components of the client layer. They can add new data to the platform but they can not delete existing data. Newly subscribed users must be manually approved by an administrator. The administrator has all the privileges to edit platform data.

\(^4\)https://github.com/SimoLoca/Pignoletto_platform

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3https://www.pignolettomibinfn.it/il-progetto
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4.1. Map

The Map is displayed as a Web Map Service application built using a custom version of the Lizmap API. It is built on top of a QGIS server that displays the information contained in a QGIS project on a geographical map. It includes several Lizmap tools that allow the user to interact and explore the data. Table 1 describes these tools in detail. For instance, it is possible to filter data on the basis of their properties, to show the information about the collected data in a tabular way, etc.

The QGIS project rendered through the Map is created by the middle layer when the platform is started. Contextually, the middle layer creates a Lizmap JSON configuration file for setting up the Lizmap parameters. Data inserted, modified or deleted during the lifecycle of the platform are immediately available (or hidden in the case of deletion) on the Map as soon as the operation is completed.

Figure 2 shows four examples of interactions with the map. In (a) it is possible to see the base map brought by OpenStreetMap; in (b) the user has selected the visualization of a raster layer; in (c) the user zoomed on a field for observing the acquisitions.

4.2. Tabular

The Tabular displays data in tabular format. It is composed by two pages for handling respectively the acquisitions \( L \) and \( D \). Figure 3 shows an excerpt of \( L \) samples. In this context, each lab sample is characterized by a numerical id, the position expressed in latitude and longitude and all the chemical properties related to it. To make the visualization of the samples more effective, the last column includes a graphical plot of the hyperspectral signal instead of the raw values.

While the map is visible without authentication, the Tabular is accessible only to registered users. Among them, two types are identified: the normal users, who can view, filter, sort and download data and the administrators who can go...
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Figure 3: Closeup of the Tabular interface. Each sample is identified through an id and spatially located by its GPS coordinates. Each sample is characterized by its soil properties and by its hyperspectral signal, here reported graphically for a better user experience.

Table 1
Utilities included in the web-map.

For convenience, the API is included in the same Flask web app of the Tabular as the two elements share several functions. It has been implemented following a REST (Representational state transfer) style whose principle nicely fits with the HTTP protocol used for communication.

The JSON Web Token (JWT) open standard is used to improve the security of the system. In first place the user authenticates into the system and receives, through an HTTP response, a token that represents its identity. Further on, this token enables the use of API capabilities.

An example of the API usage is presented in Fig.4. In this example, we show the communication flow between the user, or an acquisition device, and the platform. In first place, the user requires the authorization to interact with the database through the middle layer, and in second place it performs a single and massive data uploading.

4.4. Database

The database is designed to handle registered users, laboratory (L) and drone (D) acquisitions as well as machine learning predictions and remote sensing rasters. Figure 5 shows the logical organization of the platform database with the main entities and relationships between them.

Let $s_L$ and $s_D$ be respectively two samples of $L$ and $D$. $s_L$ and $s_D$ are located by means of geographic coordinates (latitude and longitude). They can belong to zero as well as multiple sites. A site is a logical grouping of acquisitions, such as a sampling campaign or a field.

Each $s_L$ consists of a hyperspectral signal associated with the measurement of one or more soil variables. This flexibility allows the set of soil properties considered to be modified at any time. For example, separate acquisition campaigns considering different sets of variables can be modeled seamlessly in the system. These samples constitute the set of data used for the training of supervised predictors.

Samples $s_D$ are not associated with soil properties. In fact, they represent specimens loaded at test time that require prediction by a predictive model. For this purpose, they are associated in the database with one or more estimates that in turn are associated with the model that made them, in combination with the variables that were predicted by that model. This allows different variables to be predicted by multiple predictive models.

Table: Utilities included in the web-map.

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6https://datatables.net/
7http://benpickles.github.io/peity/
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Figure 4: High-level flow of API’s execution. On-board devices and users can interact programmatically with the system through the API. After the logging procedure performed through token, single or massive upload of acquisitions can be performed.

Each raster is represented through a piramidal view in order to decrease the loading time. Each raster is therefore represented by a meta table that contains the information of each layer of the pyramid associated to the proper level of zoom. We also designed the table RasterMaster to keep track of all the rasters in the system, with the possibility to disable the visualization of a raster at runtime.

The platform database has been developed in PostgreSQL. To support georeferenced data, we enriched the suite adopting PostGIS. This extension allows the use of geographic objects following the specifications from the Open Geospatial Consortium (OGC) 8.

5. Deployment

The server is hosted on an Ubuntu 20.04 machine composed by an ASRock Z68 Extreme3 Gen3 motherboard and an Intel(R) Core(TM) i5-2500K CPU @ 3.30GHz. All code is included in a Docker image containing all the dependencies. The web server used is NGINX. A DNS record has been binded to the server ip to make the platform easily accessible through the URL http://pignoletto.lombardia.it.

6. Usability

Two usability tests were performed to evaluate the ease of use of the Map and the Tabular components. The first one is a task-driven survey (TDS) containing the 11 questions showed in table 3. Each question asks to perform a task and assess the easiness of doing it. In this case, the higher is the score, the better is the goodness. The second one is the System Usability Scale (SUS) [30]. For odd questions, the higher the better. At the contrary, for even questions, the lower the better. 10 users were involved in the usability assessment. Figures 6(a) and (b) show respectively the results of the TDS and the SUS surveys. Both evaluations demonstrated that the Map and the Tabular are easy to use and the learning curve is low. From the analysis of the replies to question 3 of TDS, it emerged that users prefer more levels of zoom, which has been corrected after the evaluation.

7. Conclusions

In this paper we presented to the state of art a new platform for handling and processing airborne and proximity data. It also capable of integrating predictive models and their relative predictions. The presented tool intends to support all stakeholders related to the agricultural sector in adopting the best practices of PA with the aim of improving the entire agricultural production chain. Although it is initially
published to support the specific needs of the Lombardy region, the platform is easily extendable to other locations with different needs, thus making it a software exploitable for any purpose. The usability assessment that we performed in section 6 showed that the presented system is easy to use and the learning curve is low. Those factors, in combination with the technical gain offered by the platform, suggest that the presented system can bring a noticeable impact on the agricultural sector thanks to its effective utility and ease of use. Thus, supporting the transition to PA techniques to make agriculture more efficient, sustainable and less impacting on the environment and climate.

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Conflict of Interest

No conflict of interest exists: We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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Current code version | 1.0
Perma link to code/repository used for this code version | https://github.com/SimoLoca/Pignoletto_platform
Legal Code License | MIT
Code versioning system used | Git
Software code languages, tools, and services used | Python, Javascript, CSS, HTML, PHP
Compilation requirements, operating environments & dependencies | Docker
If available Link to developer documentation/manual | https://github.com/SimoLoca/Pignoletto_platform/wiki
Support email for questions | s.locatelli29@campus.unimib.it

**Table 2**
Code metadata description

| Map | Display the acquisitions relative to the Argilla variable under the group lab_acquisition. Zoom on a point and click on it to view its value. How hard is this task? |
|     | Open the tabular visualization ("Dati" tool on the left sidebar) and click on the button relative to the Argilla acquisitions to open the table. Locate the sample DL-06 in the table and click the lens icon to view the corresponding point on the map. Click on the found point to view the relative info on the left panel |
|     | Zoom out to have all the acquisitions (points) on the screen visible. Search all the samples that contain a level of Argilla between 200 and 400 (use the "Filtro" tool on the left sidebar) |
|     | Display the raster slope (it can take some time to load) |

| Tabular | Download the dataset about Laboratory acquisition |
|         | Filter the samples that have been acquired in Lodi |
|         | Sort the "sito" column on the Laboratory acquisitions in descending order |
|         | Go to the Drone acquisition page, try to filter the samples that have been acquired from April 5th 2022 to May 14th 2022 |

| General | How user-friendly is Pignoletto platform map interface? |
|         | How user-friendly is Pignoletto platform tabular interface? |
|         | Do you think this application can provide valuable support for precision agriculture? |

**Table 3**
Task driven questions

**Appendix**

**Code Metadata**
Table 2 contains the metadata of the code described in this paper, with all the information necessary for the download.

**Questions of task-driven assessment**
Table 7 contains the questions posed to the users in the TDS test.