EEMstudio: an open-source freeware QGIS plugin for processing, modelling and inversion of electric and electromagnetic data

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SUMMARY

The typical workflow in electric and electromagnetic methods includes the acquisition of the data, processing of the received signal and inversion to achieve a model of the electrical properties of the ground. The data processing is a crucial step that defines the outcome of the resulting model. The electromagnetic method, in fact, as well as the induced polarization in galvanic acquisitions, is particularly susceptible to the systematic noise caused by anthropogenic infrastructures. Therefore, it is mandatory to remove the noised data in order to retrieve reliable models. The standard method for this task is the visual culling of the data that are most affected by noise and interferences (the so-called outliers), through software with graphical user interfaces designed with this specific aim.

EEMstudio is a QGIS plugin that allows to visualize electric and electromagnetic data, to select and remove outliers, as well as modelling data and launch inversions though the modelling and inversion kernel EEMverter, keeping always a link to the map during the process.

EEMstudio is composed by a docked widget in QGIS where the soundings are plotted, a main window for data processing, equipped with ad hoc plots to visualize the data, and other windows for launching forward modelling on synthetic data as well as inversions, having all the useful tools in a minimum space. Furthermore, EEMstudio is distributed as a freeware and open-source tool, accessible to anyone and editable to suit new necessities, under the EUPL 1.2 free software licence.

Key words: QGIS, processing, modelling, inversion, QC.

INTRODUCTION

In electric and electromagnetic (EM) methods, the processing phase between data acquisition and inversion is a crucial step in the workflow. Without a proper evaluation of the data included in the inversion, outliers may generate erroneous inversion models that do not reflect geology. This is especially relevant with EM and induced polarization (IP) measurements that are particularly affected by coupling with man-made metal structures, altering the response of the ground and producing artifacts in the models if not properly removed.

Furthermore, IP measurements in environmental applications are often characterized by a low signal-to-noise ratio, making the processing step crucial to retrieve the desired results. Despite the existence of automatic processing algorithms, the preferred method to process data and perform a quality control remains the visual inspection and culling of the data. Hence the need to have an interface to perform this task.

Nowdays the market is very well stocked with inversion softwares and tools for electric and electromagnetic data: among the most used for EM data we can mention AarhusInv (Auken et al., 2015), SimPEG (Cockett et al., 2015), the GA-AEM programs (Brodie, 2016) and EMagPY (McLachlan et al., 2021); for galvanic data examples are RES2DINV/RES3DINV (Loke, 2004), ResIPy (Blanchy et al., 2020) and pyGIMLi (Rücker et al., 2017).
However, fewer choices are available for data processing. The most complete option both for electromagnetic and electric data is Aarhus Workbench (Auken et al., 2009b), which uses AarhusInv as inversion kernel (Auken et al., 2015) and uses an integrated GIS for data inspection. However, Aarhus Workbench is an expensive commercial software that does not allow modifications by the users.

EEMstudio has been developed to be a freeware and open-source Graphic User Interface (GUI) in the form of a QGIS plugin for processing, modelling and inversion of electric and electromagnetic data, all in one place. It has been developed to be available for academic, teaching and professional use, and being open source, under license EUPL 1.2, it is possible to interrogate, adapt and customize the source code to the user's need. In the following, the sources of systematic noises are described, together with the typical processing steps; subsequently, EEMstudio is illustrated in all its parts.

DATA PROCESSING

The EM method, as well as galvanic induced polarization, are particularly susceptible to inductive coupling. Inverting raw data, keeping the coupled data distorted by the presence of anthropogenic infrastructure, produces artifacts in the resulting models, with the risk of being erroneously interpreted as geological features. In particular, the presence of metallic man-made structures causes buried conductors in the models; the random noise instead causes spotted appearance at depth or deep conductors, affecting also the resistivity of the intermediate parts of the model because of the vertical constraints that are used in the inversions (Viezzoli et al., 2013). Therefore, it is essential to recognize these interferences and carefully remove their effect in order to achieve reliable models.

Typically, an AEM dataset requires a three-step processing: i) automatic processing (averaging and filtering) of the navigation data; ii) automatic processing of voltage data and calculation of standard deviations based on data stacks; iii) manual refinement and quality control of the automatic processing. A fourth step can consist in a fast inversion using a smooth model to improve the previous ones (Auken et al., 2009).

In areas with extensive man-made infrastructures (power lines, metal fences, roads, pipes) voltage data need a careful manual evaluation with the support of the georeferenced map to remove coupling effects before being averaged. Coupling is either galvanic or capacitive: galvanic coupling happens when the conductor is in galvanic contact with the ground and behaves like a LR circuit; capacitive coupling is due to the presence of buried insulated conductors that leaks current in the subsoil through displacement currents, forming a LCR circuit (Danielsen et al., 2003). Galvanic coupling shows up as a local rise in the voltage data, while capacitive coupling as oscillations and possibly change of sign (Auken et al., 2009). Usually, all the data that are included within a distance of 100-150 m from the infrastructure have to be removed (Auken et al., 2009). More specifically, in the case of power lines, their effect depends on the resistivity of the ground pathway between the base of the power-line poles, as well as on the quality of the grounding of the poles themselves (Kang et al., 2021).

The other feature to be careful about in the processing step is the late-time noise. It represents the ambient noise, which is evident when the signal drops below the noise level and starts to oscillate toward the ends with changes of sign. (Viezzoli et al., 2013). Before removing this final part of the soundings (referred as denoising), averaging filters with a trapezoid shape, narrow at early times and wider at late times, are applied to the decoupled dataset (Auken et al., 2009). This operation ensures an increase of the S/N (signal-to-noise) ratio at depth, reducing the high-frequency features caused by background noise.

EEMstudio

EEMstudio has been designed to have in the same place a processing tool, an interface to launch inversions and visualize them and an app to forward model data, all while having a connection to a georeferenced map.

GIS

The link between the data and where it was acquired is a key feature, on which a large part of the quality of the processing depends. We chose QGIS as the base of the tool, as it is the most widespread open-source Geographic Information System (GIS) software available. In QGIS, EEMstudio starts as a docked widget (Figure 1), where the user can upload the processing and inversion files. It automatically loads the positions of the soundings in a QGIS project. Additionally, also the positions of the soundings that are shown in the plots are constantly shown in QGIS map as temporary layers, to locate them in real time.

Processing

For the processing, it has been developed a graphic interface (GUI) to visualize data and to perform an accurate processing of various kinds of data, such as transient EM data (airborne and ground-based), time-domain induced polarization data and galvanic data.
EEMstudio was created after experiencing processing with other codes and adapting it to the needs and experience of the research group. Therefore, the user is provided with many plots, linked to the QGIS map, to have a better overview of the data. Processing is made by the usage of a vast range of shortcuts that reflects all the necessities that could arise during processing, based on personal experience and other user's feedbacks, ensuring a quick and optimized processing phase.

EEMstudio processing window (Figures 2 and 3) is composed by the plots in which the data are visualized, selected and processed. The plots in the central part of the widow can be changed with different configurations.

The plot in the upper part of the window is Positions, where the elevation or flight altitude is shown. Additionally, measures of pitch, roll and yaw can be added to the plot.
Under this plot there are Patchwork (Figure 2) and Data Stripe (Figure 3) plot types. Both plot types show the decays' values gate-by-gate for a number of soundings. In Patchwork the sounding number (or the flight time, depending on the setting choice) is plotted on x axis, the gate number on y axis, with data values represented in colour scales. Culled-out data are coloured in grey (no culled data are shown in Figures 2 and 3, to highlight the noised data).

In Patchwork visualization (Figure 2), raw data does not provide direct information about conductivity or depth, because it is dependent by the resistivity of the layers that are investigated, but it's useful to observe spatial patterns of the measured response and possibly identify where the signal is affected by infrastructures or noise (Viezzoli et al., 2013).
In Data Stripe (Figure 3) the sounding number (or the flight time) is plotted on x axis, and $\frac{(dB/dt)}{(NiA)}$ (other choices are ρ_a or dB/dt) values on y axis Positive data are plotted in blue, negative in red, culled-out in grey. The plot on the right panel shows the $\frac{(dB/dt)}{(NiA)}$ (or ρ_a or dB/dt) decays that can be selected in the Data Stripe/Patchwork. Like in Data Stripe, positive data are plotted in blue, negative in red, culled-out in grey.

Modelling

Within EEMstudio an interface to manage easily modelling and inversion will be provided. The modelling part will be useful for educational purposes, like the modelling software EMMA (Auken et al., 2002) but also to build or modify 1D/2D/3D starting models for the inversions.

For the inversions part, it will be possible to launch 1D/2D/3D and joint inversions using EEMverter (Fiandaca et al., 2023), the freeware software for electric and electromagnetic methods developed by the EEM Team for Hydro & eXploration.

CONCLUSIONS

EEMstudio brings to the scientific community a tool for visualization, processing, modelling and inversion of AEM data, ground EM and galvanic data. It is a free alternative to the commercial software that dominate the field. Being open source, the user has also the opportunity to modify and improve it, with huge development possibilities. Functioning within QGIS, it allows to use the most widespread open-source GIS software during the processing, keeping all the main workflow in one place.

The processing app is equipped with a variety of plots to have a well-rounded understanding of the data and is optimized for a quick and straightforward processing. Furthermore, from the modelling app is possible to launch easily inversions with an intuitive and user-friendly GUI.

EEMstudio is a recently born project, still in development but ready to accommodate new modules, making it a canvas for everyone idea.

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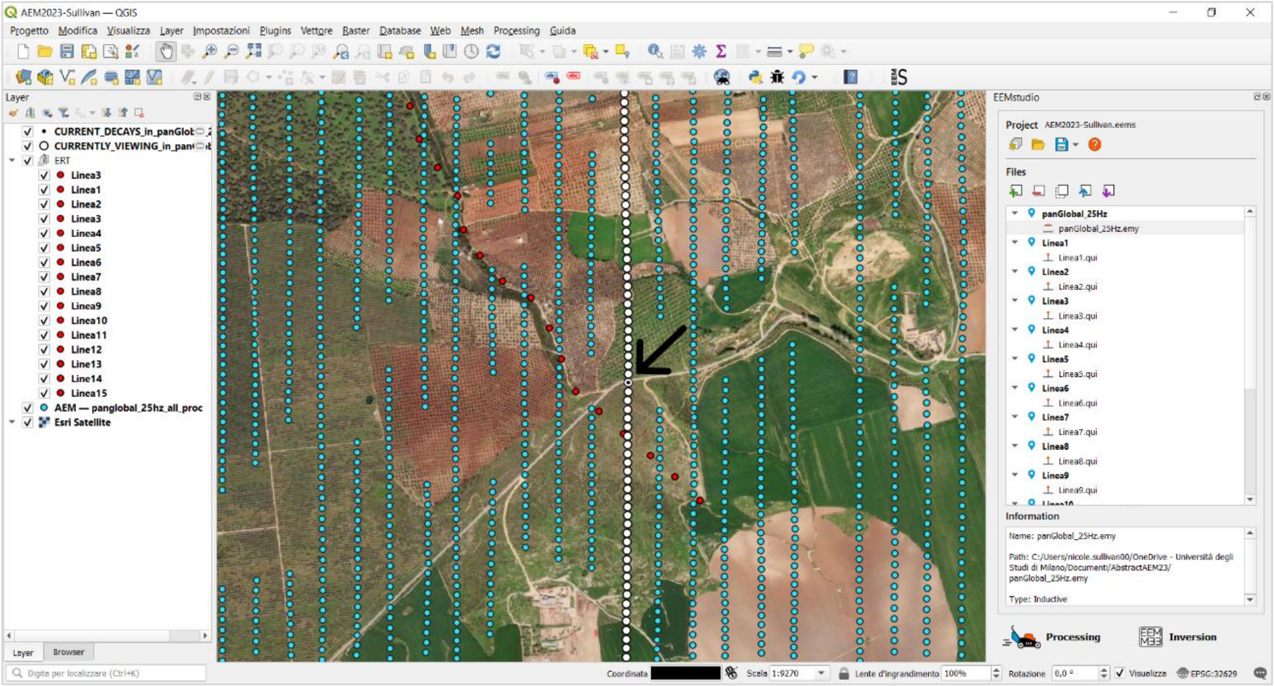

Figure 1. QGIS main window with EEMstudio plugin on the right, i.e. the docked widget. There the user can upload the processing and inversion files. The layers containing the acquisition positions are automatically added to the QGIS project. Blue dots are AEM soundings, red dots are electrodes of galvanic soundings. The white dots are all the AEM soundings shown in EEMstudio processing window and the ones with a smaller black dot inside (where the arrow points) are the soundings shown in Decays (right panels in Figure 2 and Figure 3).

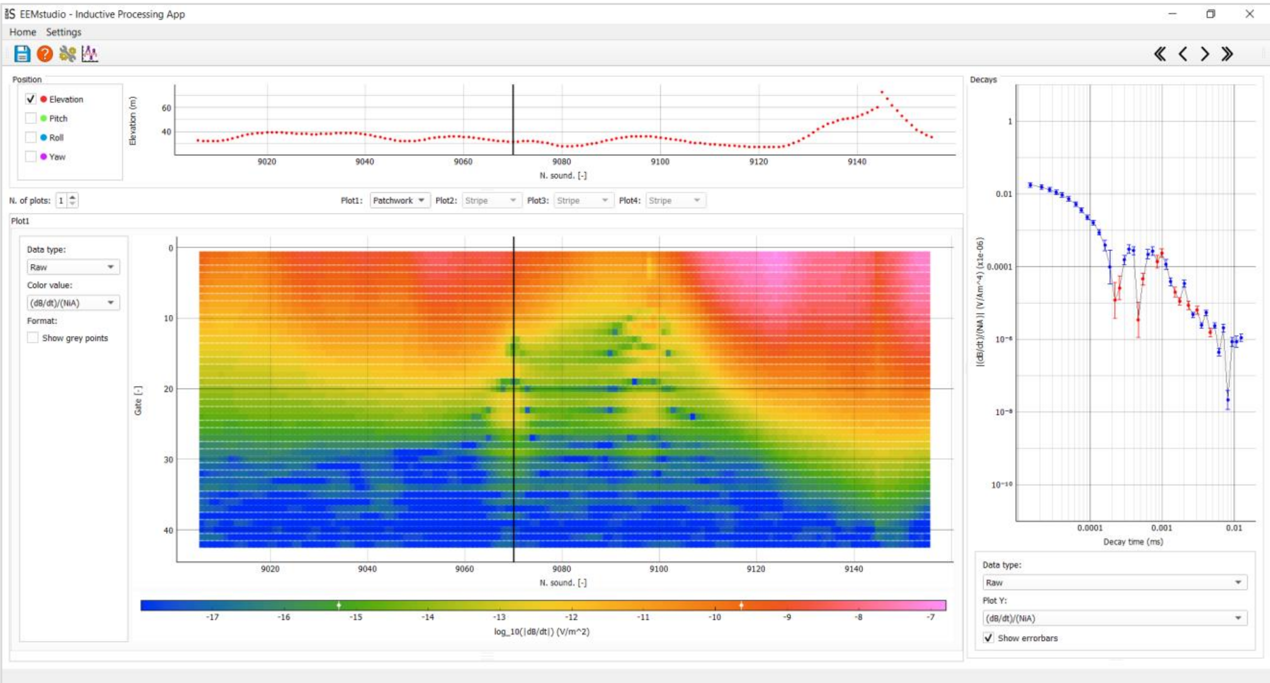

Figure 2. EEMstudio processing window – Patchwork view. In the plot in the centre top the elevation of the acquisition points is plotted against the sounding number or acquisition time. In the bottom plot the decays are plotted gate by gate against sounding number or acquisition time, and represented with a colour scale that indicates the value of $\frac{(dB/dt)}{(NiA)}$ or dB/dt or ρ_a (in this figure the data are not culled out to highlight the noise). The plot on the right are the decays of $\frac{(dB/dt)}{(NiA)}$ or dB/dt or ρ_a. All the soundings that are present in the Patchwork are plot with white dots in the QGIS map; the decays shown in the right panel with an additional black dot inside (Figure 1).

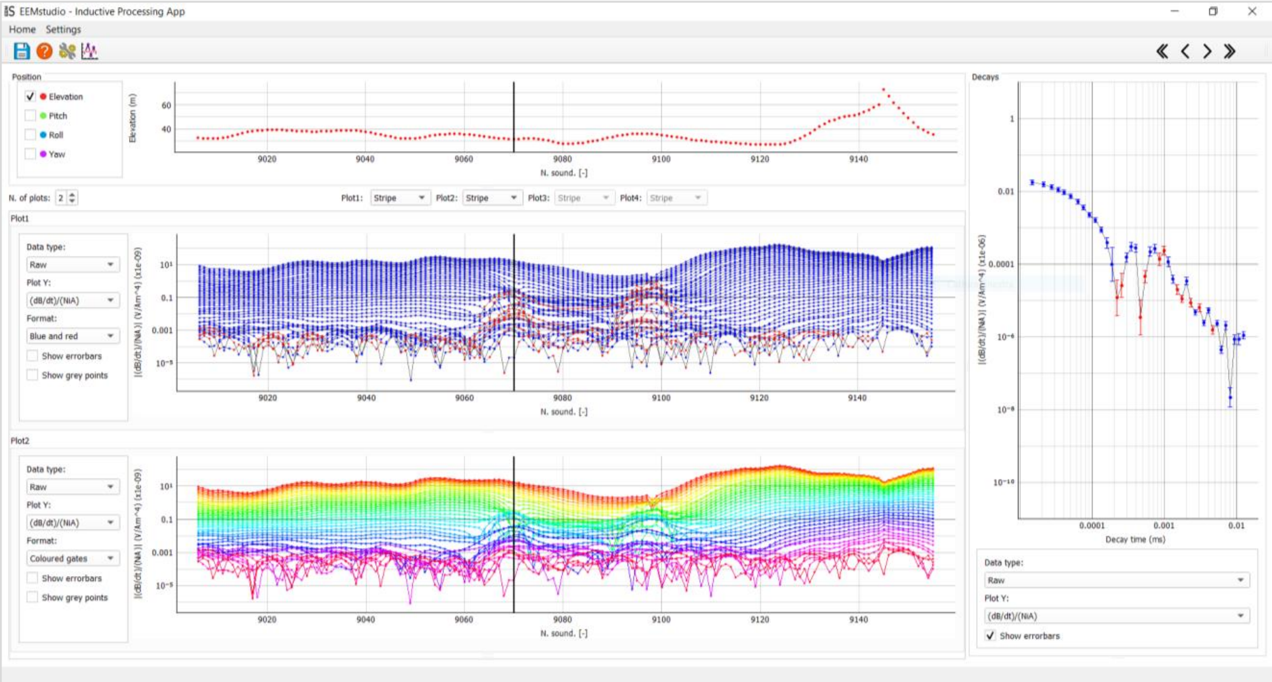

Figure 3. EEMstudio processing window – Data Stripe view. In the plot in the centre top the elevation of the acquisition points is plotted against the sounding number or acquisition time, as in Patchwork view. In the centre and bottom plots the decays are plotted gate by gate against sounding number or acquisition time, with two choices of representation: in the centre plot as blue dots if positive, red if negative and grey if culled out; in the bottom plot with gate-by-gate colouring. The plot on the right panel shows the decays selected in the Data Stripe as $\frac{(dB/dt)}{(NiA)}$ or dB/dt or ρ_a. All the soundings that are present in the Data Stripe are plot with white dots in the QGIS map; the decays in the right panel with an additional black dot inside (Figure 1).