Latest developments of OhmPi: towards small-scale ERT surveys and monitoring experiments in the field

A. Watlet[1], R. Clément[2], G. Blanchy[3], F. Camus[1], V. Dubois[2], Y. Fargier[5], N. Forquet[2], H. Guyard[4], A. Imig[2], V. Quatela[4], O. Kaufmann[1]

[1] University of Mons, Geology and Applied Geology [2] INRAE, REVERSAAL Research Unit
[3] Flanders Research Institute for Agriculture, Fisheries and Food (ILVO) [4] Institut des Géosciences de l'Environnement (IGE), Grenoble [5] Université Gustave Eiffel, GERS-RRO, IFSTTAR

Introduction

Geoelectrical imaging is increasingly being used as a tool complementing conventional ground investigations in engineering geology, hydrology and environmental sciences applications. In the last decade, geoelectrical monitoring has also become more popular for studying and monitoring physical processes such as water infiltration (Slater and Binley, 2021), landslides (Whiteley et al. 2019), etc. As novel applications emerge, the need for more accessible and flexible acquisition systems grows. The OhmPi project (Clement et al, 2020; https://gitlab.irstea.fr/reversaal/OhmPi) aims to develop an open-source, open-hardware, low-cost, low-power resistivity meter, particularly designed for humanitarian or not-for-profit organisations and for the research community. On a research level, the flexibility of this open-source system makes it particularly suitable to investigate novel acquisition strategies or design complex monitoring experiments. This is mainly where the OhmPi project stands out from commercial instruments, which are practical and robust but may lack some flexibility when it comes to designing unconventional surveys. But how reliable can such an open-source system be compared to more conventional approaches, and which accuracy should be expected? This is what we will detail here, with a focus on the field-scale measurement capabilities of the OhmPi v2024 which is the development version of OhmPi and will be released in early 2024. First, we review the updated specifications of the system and investigate the performance and measurement ranges, then we present results from small-scale field surveys including comparisons with a commercial system and finally we highlight the monitoring capabilities through a monitoring experiment of water infiltration at the Rochefort Cave Observatory (Belgium).

OhmPi v2024 specifications

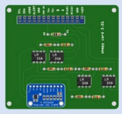
The OhmPi instrument consists of an acquisition board managing the current injection and voltage readings, a series of multiplexer boards (MUX) addressing the electrodes, a digital power supply, all connected to a Raspberry Pi controlling unit. The hardware schematics and the list of electronic components for the acquisition board and MUX boards are openly available on the project repository, while the project documentation provides guidance on how to mount a system from scratch. The costs associated with the components, the manufacturing of the PCB boards and the assembly of the OhmPi are relatively low (~3000 € for an OhmPi v2024 system with 64 electrodes).

As shown in Table 1, the latest development version of OhmPi (v2024) comes with a series of new features which are summarised below:

- On the acquisition board, the voltage reading module (Rx) is now completely isolated from the rest of the circuit and makes voltage readings on a floating ground allowing larger current injections. For the isolation, we used an I2C isolator from Mikroe (I2C Isolator Click), based on an optical isolation technology (ISO1540). For current readings, we rely on a Mikroe module (Current 7 Click), based on a bi-directional current sense amplifier (INA282), which simplifies theassembly and improves the measurement.
- The Tx and Rx isolation makes it possible to measure IP and SP as the voltage readings during no injection are more stable than in previous versions of the hardware.
- A programmable digital power supply connected to the controller via USB makes it possible to inject voltages of up to 50 V.

- A new version of the MUX board with 32 relays has been introduced. It can address either 8 electrodes and 4 roles (a, b, m, n) or 16 electrodes and 2 roles (a, b or m, n). This new functionality will eventually enable the integration of multi-channel MUX boards on voltage measurement roles (m, n1, n2, n3, etc.), which are currently under development.

The software is written entirely in Python, and allows the system to be operated directly through custom scripts using the Python API, or through a web interface or via IoT-based dashboards (e.g. Node-RED) using MQTT protocols. This latter feature is particularly useful to design complex monitoring experiments with other sensors and instruments which can be virtually connected to one another.

Parameters	 **v1.0x** (Clément et al.2020)	 **v2023.0.0** Stable version	 **v2024.0.0** Development version
Electrodes	32	4 – 64	4 – 128
Temperature of use	0 – 50°C	-20 – 70°C	-20 – 70°C
Injected Voltage	9 V	12 V	0 – 50 V
Battery	12 V	12 V	12V
Current	0 – 50 ± 0.1mA	0 – 400 mA ± 0. 1mA	0 – 500 mA ± 0. 1mA
Min pulse duration	150 ms	150 mS	150 mS
Input Impedance	36 MΩ	78 MΩ	1 TΩ
Graphical User Interface	No	Yes	Yes
IoT interface	No	Yes	Yes
SP	No	No	Yes*
IP	No	No	Yes*
Min sampling window	N/A	N/A	2 ms

*software development needed

***Table 1** Main specifications of OhmPi, including the development version OhmPi v2024*

Test cases: system performance and field capabilities

The new board of OhmPi has been tested in the lab using a reference resistors circuit with a main resistor representing the resistance of the ground and secondary resistors representing the contact resistance between virtual electrodes and the ground. The main goal is to identify an ideal measurement range for which the deviation between the measured resistance and the reference resistance is falling within an acceptable threshold of 5%. The operation has been repeated for increasing contact resistance values, in order to assess their effect on the ability of the system to accurately measure voltage and current. An ideal measurement range for which the contact resistance value does not influence the readings is found for resistance between 2 and 2000 Ohm. For resistance values outside this range, increasing the contact resistance also increases the deviation from the reference resistance.

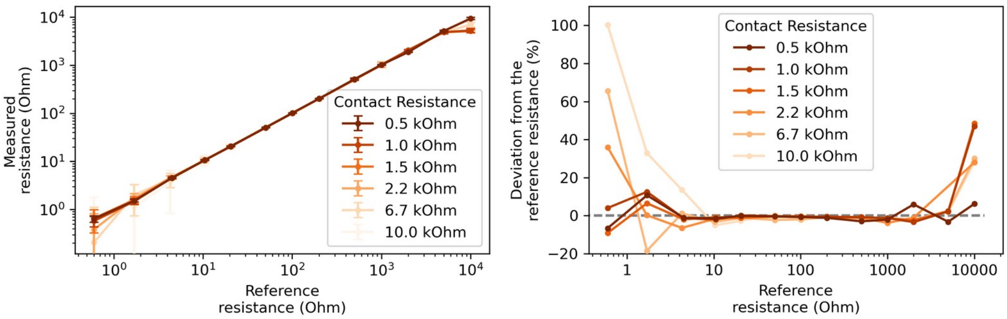


***Figure 1** Measured resistance over reference resistance as measured on a reference resistor circuit with increasing values of contact resistance, displayed as absolute values (left) and deviation from the reference resistance (right).*

Following this step, the OhmPi v2024 has been tested in the field under various conditions and the results were compared with data acquired with a commercial resistivity meter. The initial tests helped to define the optimum field conditions and measurement configurations. Figure 2 summarises three selected test cases. As can be seen for Examples 1 and 2 (Figure 2a and 2b), which represent sites on clayey and silty soils respectively, both with relatively low contact resistances (< 2 kOhm), the orders of magnitude in terms of resolution, repeatability errors, and reciprocal errors are comparable to commercial systems. This is particularly true for Wenner α or gradient arrays with an electrode spacing < 1 m and moderate geometric factors (< ~500 m). Given the reduced power capabilities of the OhmPi system, and the resolution of the voltage reading chip (ADS1115), the measurement error is inevitably higher for quadrupoles with a higher geometric factor or those with lower measured voltage (e.g. dipole-dipole). Figure 2b also displays a very clear voltage decay curve following an injection, which illustrates the IP capability of OhmPi v2024.

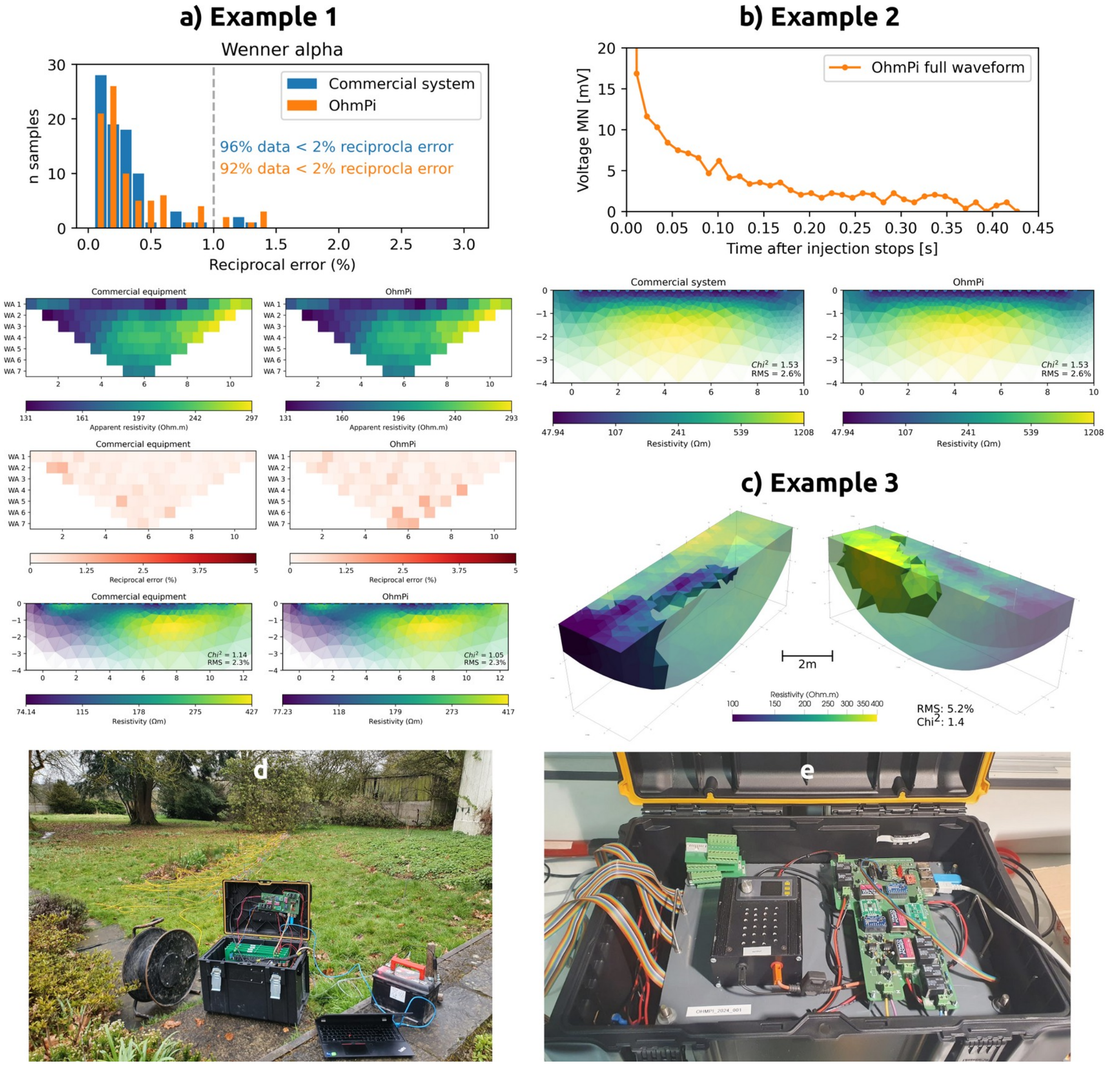


Figure 2 *Results of field tests including a) comparison bettween OhmPi v2024 and a commercial equipment (Wenner a – 16 electrodes); b) Comparisons with a commercial system and IP decay curve; c) 3D inversion example of a 96 electrodes survey; d) and e) pictures of the OhmPi v2024 set up in a rugged case for field operations. Data inverted using pyGimli (Rücker et al., 2017).*

Monitoring experiment at the Rochefort Cave Observatory

The new version of OhmPi allows optimum management of monitoring experiments on study sites. This aspect is illustrated by the deployment of OhmPi v2024 at the Rochefort Cave Observatory (Belgium) (Quinif et al., 1997) to monitor water infiltration processes in a karstic environment. The first phase of this experiment consisted of deploying a grid of 64 electrodes with 4 lines of 16 electrodes at 0.4 m spacing along the lines and 0.6 m spacing across the lines (6 x 1.8 m surface area) which aims to target the plant-soil interface. In a second phase, this grid will be upgraded to 128 electrodes. Some preliminary results are presented in Figure 3, including a high frequency monitoring over one of the four lines (Line 2) following a rainfall event.

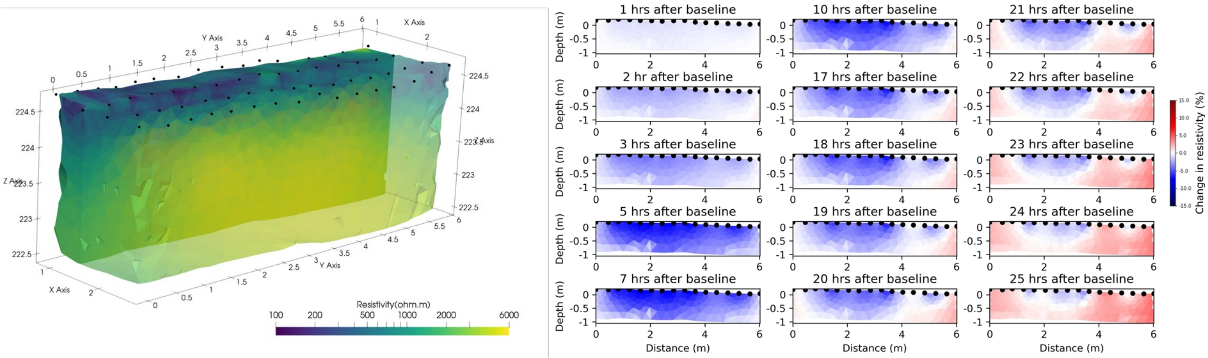


Figure 3 *Results of a static inversion (left) and 2D time-lapse inversion of Line 2 following a rainfall event which highlights changes in resistivity attributed to wetting and drying processes in the soil. Data inverted using Resipy (Blanchy et al., 2020)*

We will aslo discuss the software tools specifically developed to manage such monitoring experiment within OhmPi, including external sensors triggering of ERT data acquisition. The integration of OhmPi at the Rochefort Cave Observatory is a crucial step towards making it an open-source hydrogeophysical observatory.

Conclusions

OhmPi, an open-source, open-hardware, low-cost, low-power resistivity meter, has been developed to make geoelectrical tools more accessible, particularly for not-for-profit organisations, and to provide greater flexibility in the handling, deployment and design of research experiments in the lab or at relatively small-scale in the field. The initial test results have allowed to determine the system performance and optimum measurement ranges, as well as establish the field capabilities of the instrument. As part of the open-source philosophy, the OhmPi team is open to any new collaboration, whether for the development of hardware and/or software tools or for trialling it further in the field on a broader range of applications.

References

Blanchy G., Saneiyan S., Boyd J., McLachlan P. and Binley A. 2020. “ResIPy, an Intuitive Open Source Software for Complex Geoelectrical Inversion/Modeling.” Computers & Geosciences, February, 104423.

Clement, R., Fargier, Y., Dubois, V., Gance, J., Gros, E. and Forquet, N., 2020. – OhmPi: An open source data logger for dedicated applications of electrical resistivity imaging at the small and laboratory scale. HardwareX, 8, p.e00122.

Quinif, Y., Van Ruymbeke, M., Camelbeek, T., and Vandycke, S. 1997. Les failles actives de la Grotte de Rocheforrt (Ardenne, Bel- gique) sont-elles sismogéniques? Installation d’un laboratoire souterrain, Aardkundige Mededelingen, 8, 153–156.

Rücker, C., Günther, T., Wagner, F.M., 2017. pyGIMLi: An open-source library for modelling and inversion in geophysics, Computers and Geosciences, 109, 106-123, doi: 10.1016/j.cageo.2017.07.011.

Slater, L., and Binley, A. 2021 – Advancing hydrological process understanding from long-term resistivity monitoring systems. Wiley Interdisciplinary Reviews: Water, 8(3), p.e1513.
Whiteley, J.S., Chambers, J.E., Uhlemann, S., Wilkinson, P.B. and Kendall, J.M., 2019. Geophysical monitoring of moisture-induced landslides: A review. Reviews of Geophysics, 57(1), pp.106-145.