UNSAT-*Pi* 2 - A miniaturised flow cell apparatus for measuring the water retention curve of granular media during CT imaging

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Repository of a continuous measurement device regarding the transient and hysteretic water retention curve controlled via a Raspberry Pi single-board computer, named the "UNSAT-*Pi* 2", which can be placed in a micro-CT chamber for *in situ* CT-experiments.

The set-up was developed and used by the authors to study the water retention behaviour of unsaturated granular soils by means of X-Ray computed tomography.

The published files will not be updated on a regular basis and no further warranty is given. Users are requested to test the functionality of their applications thoroughly.

Based on Milatz (2020)[1] the set-up for the UNSAT-*Pi* 2 was modified in the framework of project 401096010 [2] [3] funded by the German Research Foundation.

The repository is structured as follows:

1. CAD construction files
2. Datasheets
3. Wiring scheme
4. Python userscript
5. Example measurement and evaluation

1. CAD construction files

This folder contains the construction files (.ipt and .pdf file format) for building the proposed flow cell. Part of the system are "Push-in L-fitting" tube connectors of the manufacturer FESTO. Those files need to be downloaded separately on the manufacturer page (account for download needed).

Furthermore, the set-up consists of an 3D printed syringe pump as described in Wijnen (2013) [5]. In this case, a NEMA 17 stepper motor is attached to the 3D printed frame and a Hamilton 1000 milliliter syringe with a teflon plunger is put into the frame.

To connect the flow cell in- and outlets with the syringe and the pressure sensors, a custom made tubing is used.

Small parts such as screws and hoses must be purchased separately.

The flow cell is made out of acrylic material.

[1] Milatz, M. (2020): An automated testing device for continuous measurement of the hysteretic water retention curve of granular media. *Acta Geotechnica* https://doi.org/10.1007/s11440-020-00922-y

[2] Heinrich, D.; Milatz, M. (planned publication in 2022): Comparison of the transient hysteretic water retention behaviour of different granular materials.

[3] DFG-Project MI 2397/1: "Microscale investigations of the hydro-mechanical behaviour of unsaturated granular soils with computed tomography" Link: https://gepris.dfg.de/gepris/projekt/401096010

[4] Heinrich, D.; Milatz, M. (2022): UNSAT-*Pi* 2 - A miniaturised flow cell aparatus for examining the water retention curve of granular media during CT imaging. doi: https://doi.org/10.15480/336.4394

[5] Wijnen B, Hunt EJ, Anzalone GC, Pearce JM (2014) Opensource syringe pump library. PLoS ONE. https://doi.org/10.1371/journal.pone.0107216

2. Wiring Scheme

The wiring scheme of the electronical parts can be taken from two files:

- unsatpi2_wiring_scheme.pdf
- unsatpi2_wiring_scheme.fzz

The latter is given in the "Fritzing" file format. fritzing [6] is an open-source hardware initiative, that published a software, where wiring schemes can be visualized in a simple and intuitive way.

3. Datasheets

This folder contains the datasheets for the electrical parts of the set-up. This assembly consists of - Honeywell 26PC series pressure sensors (in this case a pair of Honeywell 26PCAFA6G pressure sensors with a maximum measuring range of ±1 psi (about ±6.89 kPa) is used in combination with - a GSV-1L single channel amplifier developed by "ME- Meßsysteme GmbH" which connects to - an Adafruit ads1115 16 Bit Analogue to Digital Converter (ADC). - The syringe pump is driven by a Nema 17 stepper motor of type 17HS13-0404S. - The stepper motor itself is driven by a stepper driver board based on a Trinamic TMC2208 integrated circuit (or alternatively an DRV8825 driver board; various manufacturers).

4. Userscript - Controlling the UNSAT-*Pi* 2

This folder contains three python-scripts for controlling the UNSAT-*Pi* 2 - unsatpi_userscript.py - syringe_pump_calibration.py - control_syringe_pump.py

The Userscript (unsatpi_userscript.py), being the main file, is written in Python and needs to beexecuted directly on the Raspberry Pi. After execution, the script will guide the user through the process of defining the needed measurement parameters.

At the time of publishing this repository entry, the specimen's void ratio for correct calculations of change in the degree of saturation and the needed steps to be performed by the stepper motor of the syringe pump needs to be set manually in line 149 of the userscript in advance.

In a first prompt, you can choose between importing a preset measurement file or creating a new one. It's suggested to create a new one and look into the created file afterwards to get an idea of the structure. All further given information will be written into a file with the name "*_TestInfo.txt".

In the second prompt, a name for the measurement can be set.

In the third part of the script, now, an unlimited series of steps for the testing procedure can be defined. You can choose between wetting and drying steps, as well as a time for just logging without movement of the syringe pump. For a wetting or drying path, the speed of the water drainage and imbibition can be set in the unit of mm^3/s. Afterwards, the change in degree of saturation is to be given.

Important note: Keep in mind that stepper motors are supposed to be used at fairly low rotation speeds (or to be more precise: The time/delay between two (Micro)steps should not be too low). Giving values leading to low delay values will lead to an unreliable speed of the stepper motor and thus missing the set value as the software cannot keep track of the incoming data anymore. It is highly recommended to test the setup for the consistency of drainage and imbibition speeds. This behaviour can be optimised by adapting the Microstepping mode of the stepper motor in Line 70 of the script.

The just logging steps require a logging interval and a duration. If the duration is set to be 0, an (unlimited) logging duration of 10000 seconds is set, which can be stopped by using the "CTRL+C" key-combination.

If you're done defining all testing steps, select "N" for the next step of the setup procedure.

You can now review all the given information. The given flow rates are already converted to a stepper motor delay. If you're okay with the input, the measurement can be started answering the final prompt with "y".

[6] fritzing: https://fritzing.org/

The two other scripts “syringe_pump_calibration.py” and “control_syringe_pump.py” are simple auxiliary scripts, that support, as the filenames imply, calibrationg the syringe pump/the syringe and to simply controll the syringe pump for manual adjustments of the plunger.

5. Example measurement and evaluation

This folder contains three files:

- plot_WRC.py
- glass_beads_1mm_Data.csv
- glass_beads_1mm_TestInfo.txt

A Python script “plot_WRC.py” specifically adapted to an example measurement is provided besides a file of raw measurement dataset to visualise the corresponding water retention curve (WRC) of an examined specimen. Here, a specimen consisting of a packing of spherical glass beads with a mean diameter of 1 mm is used.