PhyPiDAQ

Data Acquisition and analysis for Physics education with Raspberry Pi

This is the **English** version of the documentation.

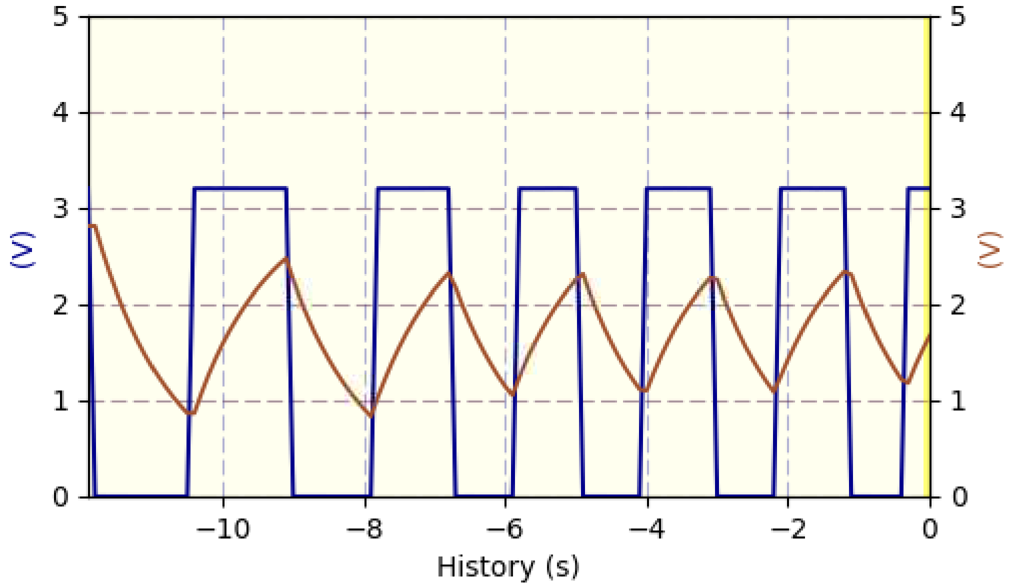
For German readers:
Die **deutsche Version** dieses Dokuments findet sich unter dem Link README_de.md bzw. README_de.pdf . Aktuelle Präsentationen zur Projekt PhyPiDAQ: http://ekpwww.etp.kit.edu/~quast/Projects/PhyPiDAQ/

This *python3* code provides some basic functionality for data acquisition and visualisation like data logger, bar-chart, XY- or oscilloscope display and data recording on disk.

In addition to the GPIO inputs/outputs of the Raspberry Pi, the analogue-to-digital converters ADS1115 and MCP3008 and PicoScope USB-oscilloscopes are supported as input devices for analogue data, as well as a number of digital sensors using protocols like I²C or SPI.

The package provides an abstraction layer for measurement devices and sensors connected to a Raspberry Pi. Dedicated classes for each device provide a simple, unified interface, containing only the methods `init(<config_dictionary>)`, `acquireData(buffer)` and `closeDevice()`. Simple examples with minimalist code illustrate the usage. The graphical user interface `phypi.py` and the script `run_phypi.py` provide a configurable environment for more complex measurements.

Fig. 1: Visualisation of the time dependence of two signals connected to an ADC



Quick-start guide

After installation - see below - a number of unified classes for data acquisition, visualisation and recording is available from the sub-directory `./phypidaq`. Each supported device needs a specific configuration, which is read from configuration files in sub-directory `./config`. The overall configuration is given in files of type `.daq`, specifying which devices and display modules to use, the readout rate, calibrations or analytical formulae to be applied to recorded data, or ranges and axis labels of the graphical output.

The graphical user interface `phypi.py` aids in the administration of the configuration options and can be used to start data acquisition. In this case, configurations and produced data files are stored in a dedicated sub-directory in `$HOME/PhyPi`. The sub-directory name is derived from a user-defined tag and the current date and time.

Data acquisition may also be started via the command line:

```
run_phypi.py <config_file_name>.daq
```

If no configuration file is given, the default `PhyPiConf.daq` is used.

The sub-directory `./examples` contains a number of simple *python* scripts illustrating the usage of data acquisition and display modules with minimalist code.

For many typical measurement tasks, preamplifiers are used to adjust the impedance (e.g. electrometer amplifier), to adjust the range levels or to amplify small signals in the µV range. A suggestion for the simple implementation of such circuits is documented in the `Hardware /` directory.

Configuration files for PhyPiDAQ

The script `run_phypi.py` allows users to perform very general measurement tasks without the need to write custom code. The options for configuration of input devices and their channels as well as for the display and data storage modules are specified in a global configuration file of type `.daq` (in `yaml` markup language), which contains references to device configuration files of type `.yaml`.

Main configuration file

A typical, commented example of the main configuration file is shown below. Note that text following a "#"-sign is ignored and contains descriptive comments or alternatives.

file PhyPiConf.daq

```
# -- Configuration Options for PhyPiDAQ
# --------------------------------------

#
# -- configuration files for hardware devices
#
DeviceFile: config/ADS1115Config.yaml    # 16 bit ADC, I2C bus
# optional:
#DeviceFile: config/MCP3008Config.yaml   # 10 bit ADC, SPI bus
#DeviceFile: config/MCP3208Config.yaml   # 12 bit ADC, SPI bus
#DeviceFile: config/groveADCConfig.yaml  # 12 bit ADC on grove RPI shield
#DeviceFile: config/PSConfig.yaml        # PicoTechnology USB scope
#DeviceFile: config/MAX31865Config.yaml  # Pt 100 sensor
#DeviceFile: config/GPIOCount.yaml       # frequency count
#DeviceFile: config/DS18B20Config.yaml   # digital temperature sensor
#DeviceFile: config/MAX31855Config.yaml  # thermo element
#DeviceFile: config/BMP180Config.yaml    # pressure/temperature sensor
#DeviceFile: config/INA219Config.yaml    # Voltage/Current sensor
#DeviceFile: config/MMA845Config.yaml    # Accelerometer
#DeviceFile: config/VL53LxConfig.yaml    # ToF distance sensor
```

```yaml
## an example of multiple devices
#DeviceFile: [config/ADS1115Config.yaml, config/GPIOCount.yaml]

# Demo options:
#DeviceFile: ToyDataConfig.yaml          # simulated data
#DeviceFile: config/ReplayConfig.yaml    # data from File

#
# -- configuration options for Channels
#
ChanLabels: [U, U]                 # names for channels
ChanUnits: [V, V]                  # units for channels
ChanColors: [darkblue, sienna]     # channel colours in display

# eventually overwrite Channel Limits obtained from device config
##ChanLimits:
## - [0., 1.]   # chan 0
## - [0., 1.]   # chan 1
## - [0., 1.]   # chan 2

# calibration of channel values
#  - null    or  - <factor> or  - [ [ <true values> ], [ <raw values> ] ]
#ChanCalib:
#  - 1.                      # chan0: simple calibration factor
#  - [ [0.,1.], [0., 1.] ]   # chan1: interpolation: [true]([<raw>] )
#  - null                    # chan2: no calibration

# apply formulae to (calibrated) channel values
#ChanFormula:
#  - c0 + c1  # chan0
#  - c1          # chan1
#  - null        # chan2 : no formula

#
# -- configuration options for graphical display
#
Interval: 0.1                # logging interval
#NHistoryPoints: 120          # number of points used in history buffer
DisplayModule: DataLogger    # history of channel signals
#DisplayModule: DataGraphs    # text, bar-graph, history and xy-view
#DisplayModule: null          # no graphical display
#Title: Demo                  # display title
#XYmode:     false            # enable/disable XY-display
## if more than two channels active:
#Chan2Axes: [0, 1, 0]         # assign channels to axes
#xyPlots:                     # define which axes to show
# - [0, 1]                    #  in xy-plot
# - [0, 2]
# - [1, 2]

#
# -- start in running or paused mode
# startActive: true  # start in running mode

#
# -- configuration options for output to file
#
```

```
#DataFile:   testfile.csv     # file name for output file,
DataFile:   null              #  null to disable
#CSVseparator: ';'            # field separator, set to ';' for German Excel

# enable buffering of latest data (depth NHistoryPoints from above)
#bufferData: PhyPiData    # file name to track latest data and eventually
#bufferData: null         #  store them, or null to switch off

# enable output to fifo (a linux pipe) to send data to other processes
DAQfifo: null
#DAQfifo: PhyPiDAQ.fifo
```

Device configuration files

Typical, commented examples of device configurations are shown below. The device configuration file for the analogue-to-digital converter **ADS1115** specifies the active channels, their ranges and single or differential operation modes.

file ADS1115Config.yaml

```
# example of a configuration file for ADC ADS1115

DAQModule: ADS1115Config    # phypidaq module to be loaded

ADCChannels: [0, 3]         # active ADC-Channels
                        # possible values: 0, 1, 2, 3
                        # when using differential mode:
                        #    -  0 = ADCChannel 0
                        #            minus ADCChannel 1
                        #    -  1 = ADCChannel 0
                        #            minus ADCChannel 3
                        #    -  2 = ADCChannel 1
                        #            minus ADCChannel 3
                        #    -  3 = ADCChannel 2
                        #            minus ADCChannel 3

DifModeChan: [true, true] # enable differential mode for Channels

Gain: [2/3, 2/3]          # programmable gain of ADC-Channel
                          #   possible values for Gain:
                          #     - 2/3 = +/-6.144V
                          #     -   1 = +/-4.096V
                          #     -   2 = +/-2.048V
                          #     -   4 = +/-1.024V
                          #     -   8 = +/-0.512V
                          #     -  16 = +/-0.256V
sampleRate: 860           # programmable Sample Rate of ADS1115
                          #    possible values for SampleRate:
                          #    8, 16, 32, 64, 128, 250, 475, 860
```

The **USB-oscilloscope** PicoScope can also be used as data logger. In this case the average of a large number of measurements at high rate is taken. Choosing a measurement time of 20 ms very effectively eliminates 50 Hz noise.

file PSconfig.yaml

```yaml
# example of a configuration file for PicoScope 2000 Series

DAQModule: PSConfig

PSmodel: 2000a

# channel configuration
picoChannels: [A, B]
ChanRanges: [2., 2.]
ChanOffsets: [-1.95, -1.95]
ChanModes: [DC, DC]
sampleTime: 2.0E-02
Nsamples: 100

# oscilloscope trigger
trgActive: false  # true to activate
trgChan: A
#trgThr: 0.1
#pretrig: 0.05
#trgTyp: Rising
#trgTO: 1000  # time-out

# internal signal generator
# frqSG: 100.E+3 # put 0. do disable
frqSG: 0.
```

Examples of other devices like the analog-to-digital converter MCP3008, of rate measurements via the GPIO pins of the Raspberry Pi or temperature measurements with the 1-wire digital thermometer DS18B20, PT100 sensors and the resistance-to-digital converter MAX31865 or thermocouples and the thermocouple-to-digital converter MAX31855 are also contained in the configuration directory, see files `MCP3008Config.yaml`, `GPIOcount.yaml`, `DS18B20Config.yaml`, `MAX31865Config.yaml` or `MAX31855Config.yaml`, respectively.

Installation of PhyPiDAQ on a Raspberry Pi

Get PhyPiDAQ code and dependencies

After setting up your Raspberry pi with the most recent version of the Debian Release *stretch*, enter the following commands in the console window:

```
mkdir git
cd git
git clone https://github.com/GuenterQuast/PhyPiDAQ
```

For your convenience, the script *installlibs.sh* installs all components needed for PhyPiDAQ. Simply execute the script *installlibs.sh* once on the command line (without text after `#`):

```
cd ~/git/PhyPiDAQ   # change to installation directory
git pull            # eventually update to latest version of PhyPiDAQ
./installlibs.sh
```

The installation is now done and *PhyPiDAQ* is ready to be used.

The last part of the inatallation procedure is also valid to update an exiting verion of `PhyPiDAQ` .

To test the installaion without connected hardware or on a system other than the Raspberry Pi, PhyPiDAQ may be started in demo-mode:

```
cd ~/git/PhyPiDAQ   # change to installation directory
./run_phypi.py      # execute run_phypi.py with configuration PhyPiDemo.daq
```

Anmerkung

Remark

PhyPiDAQ is meant to be an educational tool. Confronting students with the full contents of this package is therefore not appropriate. Instead, it is recommended to create a working directory and copy examples from there to the student's working directory. This is achieved via the following commands:

```
# create PhyPi working directory and make examples and config files available
cd ~/git/PhyPiDAQ
./install_user.sh [<directory name>]
    # the input of a directory name is optional; default is "PhiPi"
# provide icon to graphical user interface
cp ~/git/PhyPiDAQ/phypi.desktop ~/Desktop
```

You might also consider moving the *PhyPiDAQ* package to system space, e.g. /usr/local:

```
sudo mv ~/git/PhyPiDAQ /usr/local/
```

Please note that the paths in the example above must be adjusted in this case, e.g. ´~/git/` -> /usr/local/. The paths in *~/Desktop/phypi.desktop* must also be changed appropriately. This is most easily achieved by right-clicking the icon and use the dialog "Properties".

Dependencies on external packages

The PhyPiDAQ package relies on code from other packages providing the drivers for the supported devices and libraries for data visualisation:

- the Adafruit Pyhon MCP3008 library
  https://github.com/adafruit/Adafruit_Python_MCP3008
- the Adafruit Python ADX1x15 library
  https://github.com/adafruit/Adafruit_Python_ADS1x15
- the Adafruit Python MAX31855 library
  https://github.com/adafruit/Adafruit_Python_MAX31855
- the w1thermsensor library by Timo Furrer
  https://github.com/timofurrer/w1thermsensor
- components from the picoDAQ project
  https://github.com/GuenterQuast/picoDAQ
- the *python* bindings of the *pico-python* project by Colin O'Flynn
  https://github.com/colinoflynn/pico-python
- the low-level drivers contained in the Pico Technology Software Development Kit
  https://labs.picotech.com/raspbian

For convenience, installation files for external packages and for modules of this package in pip wheel format are provided in sub-directory *./installlibs*.

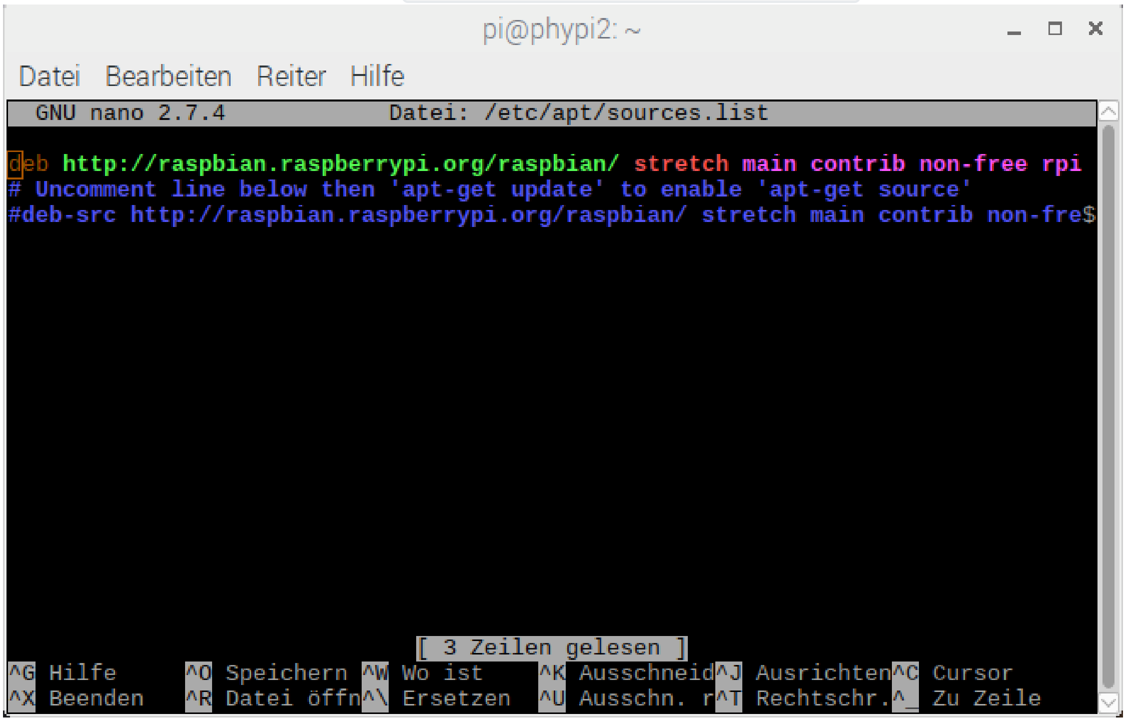
The visualization modules depend on *matplotlib.pyplot*, *Tkinter* and *pyQt5*, which must also be installed.

For completeness, the steps performed by the script `installlibs.sh` are documented here:

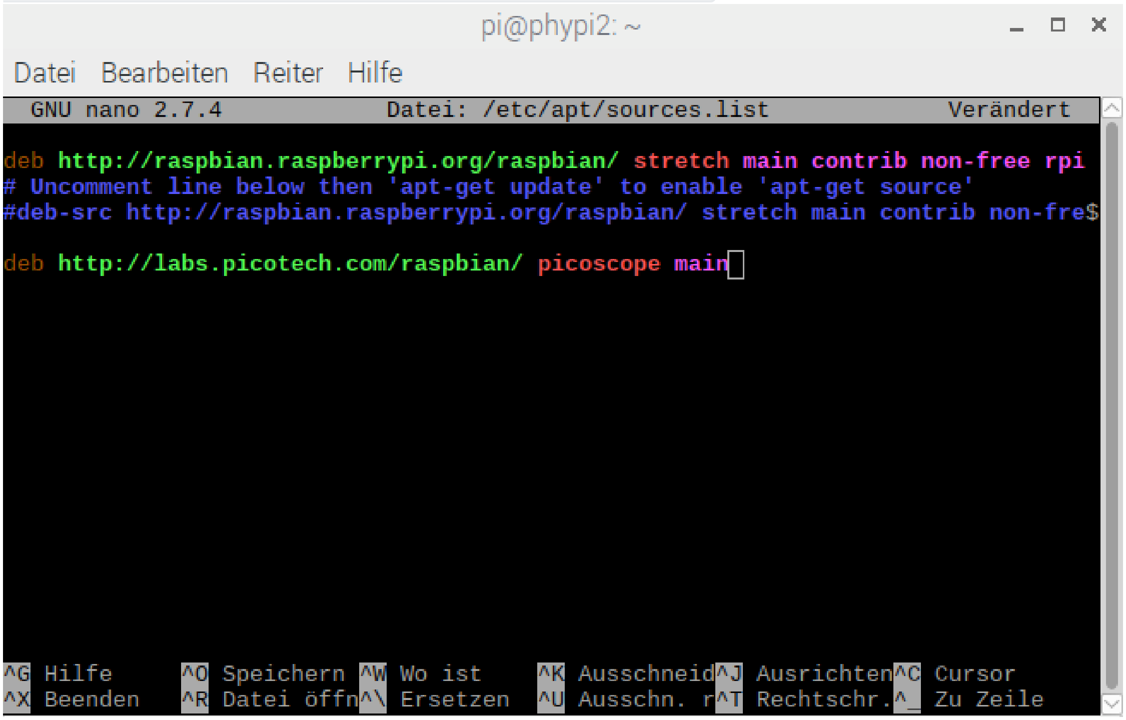
```
#
# script to install libraries PhyPiDAQ depends on
#
# -----------------------------------------------

sudo apt-get install python3-yaml
sudo apt-get install python3-scipy
sudo apt-get install python3-matplotlib
sudo apt-get install python3-pyqt5
sudo apt-get install libatlas-base-dev # needed to build nupmy

sudo pip3 install installlibs/whl/*.whl # python wheels

sudo pip3 install installlibs/tgz/*.tar.gz # python packages

sudo dpkg -i installlibs/picoscopelibs/*.deb # picoscope
sudo usermod -a -G tty pi # grant acces to USB for user pi
```

The drivers for PicoScope oscilloscopes may also be installed from the repository of the vendor, which is included as follows:

1. Open file /etc/apt/sources.list by `sudo nano /etc/apt/sources.list`.



2. Use arrow keys to navigate to the next free line and add entry `deb http://labs.picotech.com/raspbian/ picoscope main` to /etc/apt/sources.list.



3. Save file /etc/apt/sources.list by `Ctrl + O` and `Enter`.
4. Close /etc/apt/sources.list by `Ctrl + X`.

Now the drivers for drivers for the various PicoScope devices can be included end eventually updated with *apt-get*:

```
wget -O - http://labs.picotech.com/debian/dists/picoscope/Release.gpg.key |
sudo apt-key add -
sudo apt-get update
sudo apt-get install libps2000
sudo apt-get install libps2000a

# allow access of user pi to usb port
sudo usermod -a -G tty pi
```

Overview of files contained in PhyPiDAQ

Programs

- `run_phypi.py`
  run data acquisition and display modules as specified in configuration files (default `PhyPiConf.daq` and *.yaml* files ins subdirectory *config/*)
- `phypi.py`
  graphical user interface to edit configuration files and start the script `run_phypi.py`

Modules

- `phypidaq/__init__.py`
  initialisation for package *phypidaq*
- `phypidaq/_version_info.py`
  version info for package *phypidaq*
- `phypidaq/ADS1115Config.py`
  class for handling of analog-to-digital converter ADS1115
- `phypidaq/MCP3008Config.py`
  class analog-to-digital converter MCP3008
- `phypidaq/MCP3008Config.py`
  class for current and voltage sensor INA219
- `phypidaq/DS18B20Config.py`
  class for handling of digital thermometer DS18B20
- `phypidaq/BMPx80Config.py`
  class for the digital temperature and pressure sensors BMP180/280 or BME280
- `phypidaq/MMA8451Config.py`
  class for the digital accelerometer MMA8451
- `phypidaq/GPIOCount.py`
  class for reading rates from GPIO pins
- `phypidaq/MAX31855Config.py`
  class for MAX31855 thermocouple-to-digital converter
- `phypidaq/MAX31865Config.py`
  class for MAX31865 resistance-to-digital converter

- `phypidaq/PSConfig.py`
  class for PicoScope USB oscilloscopes
- `phypidaq/VL53LxConfig`
  class for VL53L1X distance sensor
- `phypidaq/TCS34725Config` class for TCS34725 RGB color sensor
- `phypidaq/AS7262Config` class for AS7262 six channel color sensor
- `phypidaq/AS7265xConfig` class for AS7265x 18 channel spectral sensor
- `phypidaq/GDK101Config.py`
  class for gamma ray detektor GDK101, FTLAB
- `phypidaq/ToyDataConfig.py`
  class to generate simulated data (for test, debugging or exercises)
- `phypidaq/ReplayConfig`
  class to replay data from file
- `phypidaq/Display`
  interface and background-process handling data visualisation
- `phypidaq/DataLogge`
  class for display of data histories and xy diagrams
- `phypidaq/DataGraph`
  general display module for data as bar graphs, history plots and xy-graphs
- `phypidaq/DataRecorde`
  store data in CSV format
- `phypidaq/pulseGPIO` class to set or pulse GPIO pin of raspberry py
- `phypidaq/runPhyPiDAQ`
  class for script `run_phypi.py`
- `phypidaq/runPhyPiUI.py` class for graphical user interface `phypi.py`, uses `phypiUI` as base class
- `phypidaq/phypyUI`

  base class for `runPhyPyUI`, generated from `phypi.ui` with `pyuic5`
- `phypidaq/phypi.ui` output of `designer-qt5` , describes the graphical user interface

Configuration files

- `phypidaq.cfg`
  global configuration for directory with configuration files and inital work directory; if this file is found in the `home` directory, it takes priority over the one in the installation directory
- `PhyPiConf.daq`
  main configuration file, depends on device configurations in sub-directory *config/*
- `config/ADS1115Config.yaml` 16 bit ADC
- `config/MCP3008Config.yaml` 10 bit ADC
- `config/MCP3208Config.yaml` 12 bit ADC
- `config/INA219Config.yaml` current and voltage sensore
- `config/DS18B20Config.yaml` digital temperature sensor
- `config/BMP280Config.yaml` temperature and pressure sensor
- ``` `config/BMP180Config.yaml ``` temperature and pressure sensor
- `config/GPIOCount.yaml` frequency measruement via GPIO pin

- `config/MAX31855Config.yaml` converter for thermocouple
- `config/MAX31865Config.yaml` converter for PT-100
- `config/INA219Config.yaml` current-voltage sensor
- `config/TCS34752Config.yaml` RGB sensor
- `config/AS7262Config.yaml` 6 channel color sensor
- `config/AS7265xConfig.yaml` 18 channel spectral sensor
- `config/VL53L1XConfig.yaml` distance sensor
- `config/GDK101.yaml` gamma-ray detector
- `config/PSConfig.yaml` PicoScope usb oscilloscope

Examples

- `examples/read_analog.py`
  very minimalist example to read one channel from an analog-to-ditigal converter
- `examples/display_analog.py`
  very minimalist example to read one channel from an analog-to-ditigal converter and display data as a history graph
- `examples/display_analog2.py`
  read two channels from an analog-to-ditigal converter and display data as a history graph
- `examples/read_INA210.py`
  read data from INA219 current and voltage sensor
- `examples/read_18B20.py`s simple example to read the temperature sensor DS18B20
- `examples/readBMPx80.py` simple example to read the digital temperature and pressure sensor BMP180/280
- `examples/readMMA8541.py` simple example to read the digital accelerometer MMA8451
- `examples/runOsci.py`
  run an oscilloscope display, configuration as specified in *.yaml* file (default is `PSOsci.yaml`)
- `examples/GPIO-In-Out.py`
  example to control GPIO pins: generate square signal on output pin from variable voltage on input pin
- `examples/poissonLED.py`
  generate a random signal following Poisson statistics on a GPIO pin
- `examples/FreqGen.py`
  generate a fixed frequency signal on a GPIO pin
- `examples/set_MPC4725`
  example to set voltage on MCP4725 ditital-to-analog converter

Configuration files for *run_phypi.py*

- `examples/Amperemeter.daq`
  display current and eventually voltage read from INA219 sensor
- `examples/Barometer.daq`
  uses BMB180 or BMP280 sensors to display temperature and air pressure
- `examples/Accelerometer.daq`
  uses MMA8451 to display x-, y- and z-acceleration
- `examples/NoiseMeter.daq`
  measure noise with a microphone connected to PicoScope USB oscilloscope; displays the *rms* of 200 samples taken over a time periods of 20 ms. Can also be used with geophone SM-24
- `examples/RGBsensor.daq` RGB color sensor
- `examples/ColorSpectrum.daq` six channel color sensor

- `examples/AS7265x.daq` 18 channel spectral sensor
- `examples/GammaDose.daq`
  measurement of gamma-ray dose with GDK101
- `examples/ToyData.daq` generation and display of simulated data
- `examples/ReplayData.daq`
  data from file (for demo mode)
- `examples/readPipe.py`
  read data from named linux pipe (*run_phypi.py* with option DAQfifo: <pipe name>)

Documentation

- `doc/Kurs_digitale_Messwerterfassung_mit_PhyPiDAQ.md (.pdf)`
  German only: Introductory course to measuring with the Raspberry Pi

- `doc/Einrichten_des_Raspberry_Pi.md (.pdf)`
  German only: setting up the Raspberry Pi for this project

- `doc/Komponenten_fuer_PhyPi.md (.pdf)`
  recommended components for this project

- `doc/Bauanleitung_Kraftsensor.md (.pdf)`
  building instructions for a force sensor

- `Hardware`
  documentation of card with analog preamplifiers
  - electrometer
  - instrument amplifier
  - level shifter
  - ... and others