Lab::Measurement – measurement control with Perl

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Flexible measurement needed?!

- Tired of following your wires in square meters of LabVIEW diagrams?
- Tired of clumsy string handling and low-level driver functions in your looong C program?
- Use a text processing language to manage your measurement! Use Perl!

```perl
#!/usr/bin/env perl
# Read out SR830 Lock In Amplifier at GPIB address 13
use 5.010;
use Lab::Moose;

my $lia = instrument(
    type               => 'SR830',
    connection_type    => 'LinuxGPIB',
    connection_options => { pad => 13 }
);

my $amp = $lia->get_amplitude();
say "Reference output amplitude: $amp V";

my $freq = $lia->get_freq();
say "Reference frequency: $freq Hz";

my $r_phi = $lia->get_rphi();
my ( $r, $phi ) = ( $r_phi->{r}, $r_phi->{phi} );
say "Signal: r=$r V, phi=$phi degree";
```

Currently supported hardware

Hardware driver backends:

- NI-VISA (MS Windows) and all hardware supported by it
- LinuxGPIB and all hardware supported by it
- TCP connection, generic network socket
- USB-TMC lightweight driver (Linux, libusb)
- VXI-11 lightweight driver (Linux, libtirpc)
- Oxford Instruments IsoBus
- Zurich Instruments LabOne API

Growing number of high-level drivers (more are *very* easy to add):

- Multimeters: HP / Agilent / Keysight
- DC sources: Yokogawa / Keithley / Keysight
- AW generators: Rigol
- Lock-in amplifiers: Stanford Research / Signal Recovery / Zurich Instruments / SyncTek
- Temperature controllers: Lakeshore / Oxford Instruments
- RF / microwave sources, spectrum analyzers, VNAs: Rohde & Schwarz / HP / Agilent / Rigol
- Nanonis Tramea
- and many more...

Key facts

- Open source / free software
- https://www.labmeasurement.de/
- License: same as Perl (GPL-1+ or Artistic)
- Releases on CPAN, development on Github
- Contributors and cooperations welcome!

Real world measurement

- Ferromagnetic resonance measurement with vector network analyzer (VNA)
- Outer loop: continuous sweep of magnetic field with OI Mercury iPS magnet controller
- Inner loop: VNA transmission measurement at multiple discrete microwave frequencies

```perl
#!/usr/bin/env perl
use 5.010;
use Lab::Moose;

# Define the two instruments
my $ips = instrument(
    type               => 'OI_Mercury::Magnet',
    connection_type    => 'Socket',
    connection_options => { host => '192.168.3.15' },
);

my $vna = instrument(
    type               => 'RS_ZVA',
    connection_type    => 'VXI11',
    connection_options => { host => '192.168.3.27' },
);

# Set VNA's IF filter bandwidth (Hz)
$vna->sense_bandwidth_resolution( value => 1 );

# The outer sweep: continuous magnetic field sweep
my $field_sweep = sweep(
    type       => 'Continuous::Magnet',
    instrument => $ips,
    from       => 2,    # Tesla
    to         => 0,    # Tesla
    rate       => 0.01, # Tesla/min
    start_rate => 1,    # Tesla/min (rate to approach start point)
    interval   => 0,    # run slave sweep as often as possible
);

# The inner sweep: set frequency to 1GHz, 2GHz, ..., 10GHz
my $frq_sweep = sweep(
    type       => 'Step::Frequency',
    instrument => $vna,
    from       => 1e9,
    to         => 10e9,
    step       => 1e9
);

# The data file: gnuplot-style, VNA data prefixed with B
my $datafile = sweep_datafile(
    columns => [ 'B', 'f', 'Re', 'Im', 'r', 'phi' ] );

# Add a live plot of the transmission amplitude
$datafile->add_plot( x => 'B', y => 'r' );

# Define the measurement instructions per (B,f) point
my $meas = sub {
    my $sweep = shift;

    say "frequency f: ", $sweep->get_value();
    my $field = $ips->get_field();

    # this is not really a VNA "sweep", but only a
    # point measurement at one frequency
    my $pdl = $vna->sparam_sweep( timeout => 10 );

    # Record the result, prefixed with B
    $sweep->log_block(
        prefix => { field => $field },
        block  => $pdl
    );
};

# And go!
$field_sweep->start(
    slave       => $frq_sweep,
    datafile    => $datafile,
    measurement => $meas,
    folder      => 'Magnetic_Resonance',
);
```

Output files

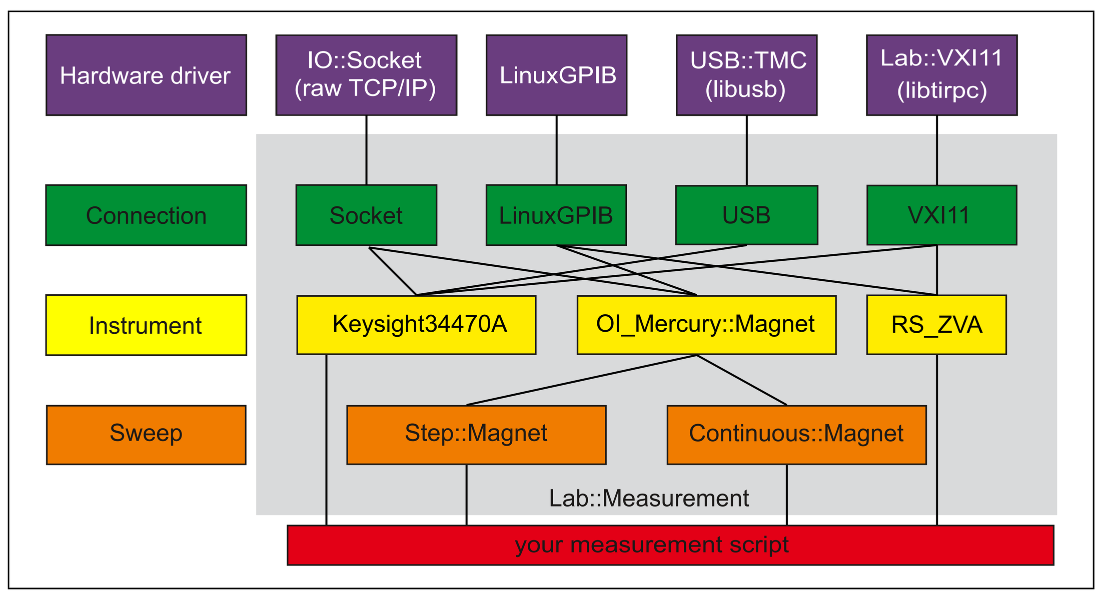
```
simon@dilfridge ~/FMR$ ls Magnetic_Resonance_001/
META.yml  data.dat  data.png  magnet-resonance.pl
```

- *META.yml:* various metadata (host, user, date, L::M version, command line arguments)
- *data.dat:* measured data, in tab-separated Gnuplot format
- *data.png:* live plot at the end of the measurement, as a png image
- *magnetic-resonance.pl:* archival copy of the measurement script

Advanced sweep features

- Multidimensional sweeps, e.g. 3D sweep: creating one 2D datafile for each step of the outermost sweep
- Log arrays and matrices of data (PDLs). Useful for spectrum analyzers, VNAs, oscilloscopes which do fast, internally controlled sweeps.
- Extensive support for live plots via gnuplot: line plots (2D data) and color maps (3D data)
- Customizing live plots: access to all gnuplot plot and curve options via PDL::Graphics::Gnuplot

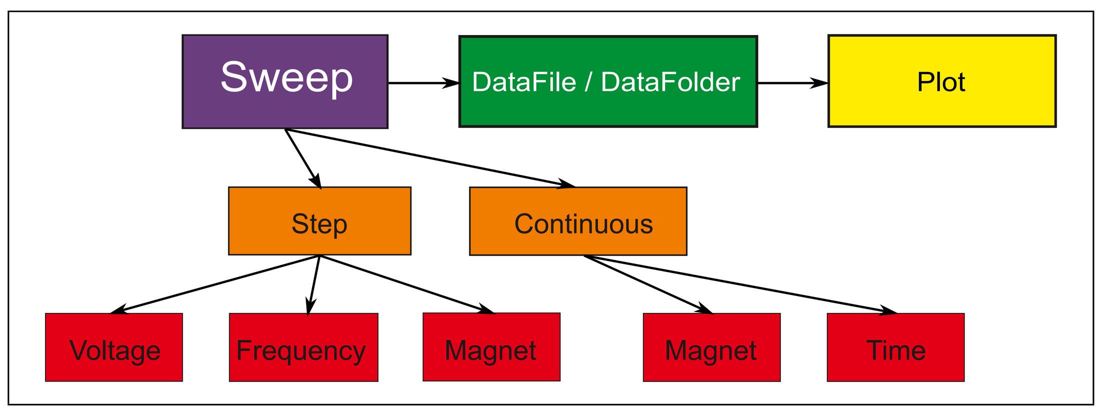
Layer structure



- Modular structure. Easy to extend with new instrument drivers and connection types
- Abstract IO layer, makes instrument drivers independent of hardware backends

High-level sweep framework

- Modern Perl implementation; use state of the art object-oriented programming



- Separate classes for sweeps, datafiles, datafolders, and plots
- Most operational details of sweeps implemented in subclasses of Lab::Moose::Sweep
- High modularity: *very* easy to extend

New improvements / additions

- VISA::USB connection: USB-TMC over NI-VISA
- Enable magnet persistent mode usage
- RFC3161 timestamps for measurement data
- New drivers
  - Andeen-Hagerling AH2700A ultra-precision capacitance bridge
  - HP 8596E, Rigol DSA815 spectrum analyzer
  - SignalRecovery 7265, Zurich Instruments HF2LI lock-in
  - Oxford Instruments Triton and ITC503 temperature control
  - Keithley 2400, 2450 sourcemeter
  - HP 34420A Nanovoltmeter
  - Tektronix TBS1000C, Keysight DSOS604A oscilloscope
  - Rigol DG5000 series waveform generator
  - Rohde & Schwarz ZNL network analyzer
  - Nanonis Tramea (work in progress)

Reference / Cite as

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