calibration_freq_to_R

May 19, 2022

1 Calibration: frequency to resistance

1.1 Hardware used

A single build `Resistive AC soil moisture sensor v1.0` PCB connected to an Adafruit ItsyBitsy 32u4 microcontroller board flashed with the following code found at: https://github.com/Dennis-van-Gils/PCB-resistive-AC-soil-moisture-sensor/tree/main/src_mcu

1.2 Calibration procedure

I apply a known resistance `R[Ohm]` over the probe terminals and measure the resulting frequency `f[Hz]`. I then perform a non-linear least-squares fit to the data to be able to transform the output frequency back to a resistance.

1.3 Used fit

The `log10(f)` vs `log10(R)` curve can be captured by an S-curve rotated by 90 degrees, also known as a `logit` function (https://en.wikipedia.org/wiki/Logit):

```
logit(p) = ln(p / (1 - p)), for 0 < p < 1
```

I add 4 fitting parameters `k`, `x0`, `b` and `a` to the logit function to be able to fit the data. Hence, what we end up with is the following C++ code to transform measured frequency [Hz] into resistance [Ohm]:

```
double p = (log10(frequency) - x0) * b;
double R_log = (k * log(p / (1 - p)) + a);
resistance = pow(10, R_log);
```

The fit is inherently monotonic.

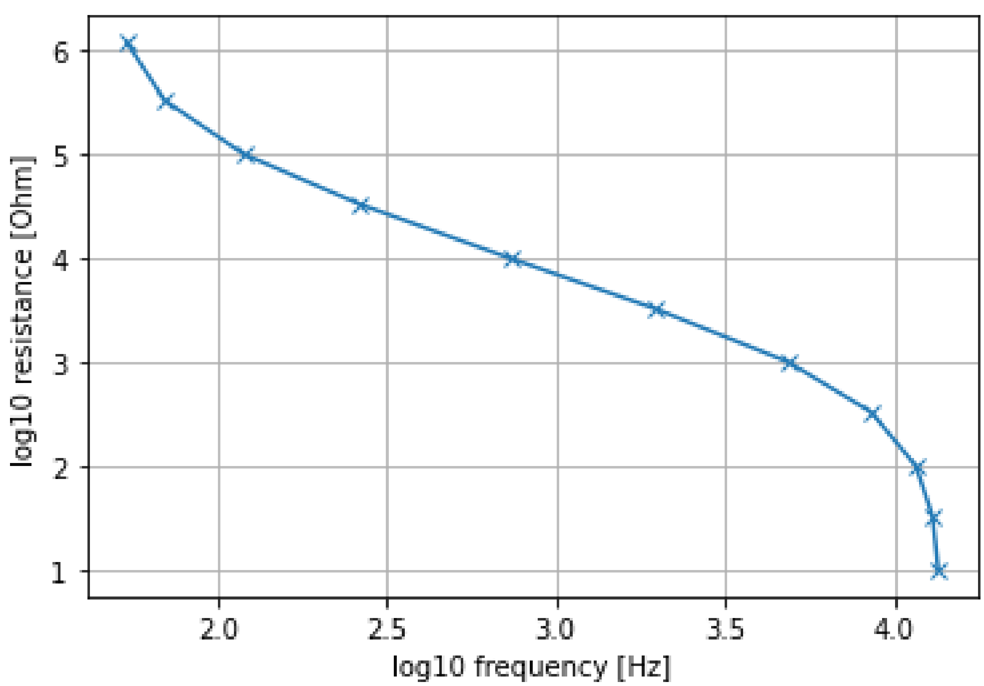
1.4 Calibration results

In this specific realization I found the following best fit results, leading to a resistance fitting accuracy of +/-20 % (at worst). It is good enough for order-of-10s estimation over the range 10 Ohm to 10 MOhm.

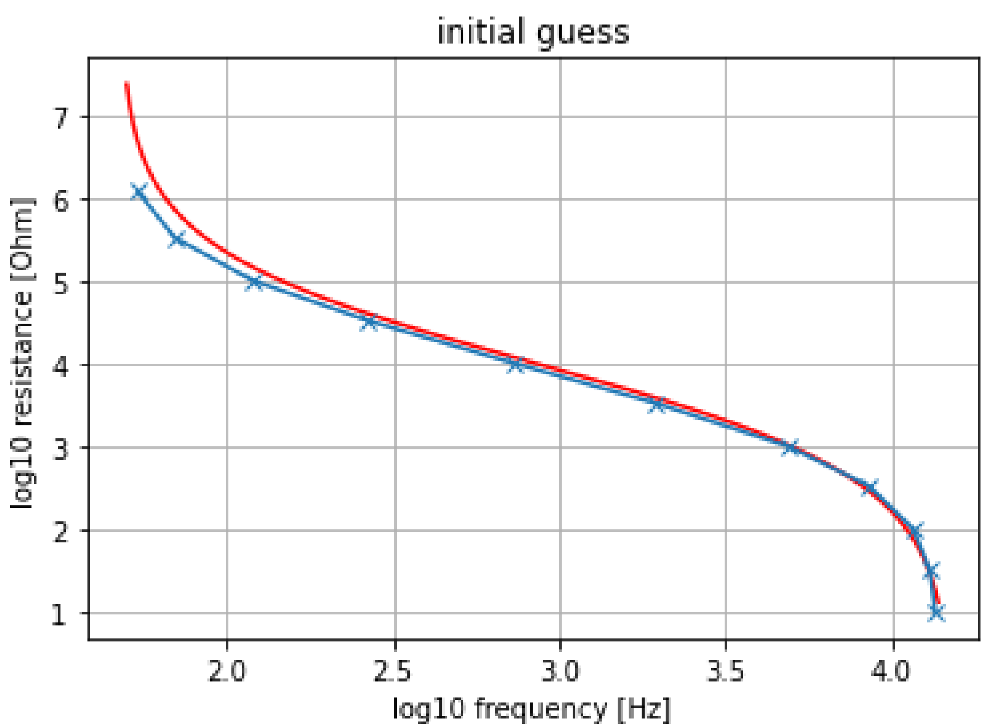
```
const double k  = -0.61404261;
const double x0 = 1.65479988;
const double b  = 0.40044114;
const double a  = 3.97842502;
```

Dennis van Gils, 19-05-2022

[1]:
```
import numpy as np
import matplotlib.pyplot as plt

# Applied a known resistance R[Ohm] and measured the resulting frequency f[Hz]
R = np.array([0.1, 10, 33, 100, 330, 1000, 3300, 10000, 33000, 100000, 330000,␣
 ↪1200000, 100000000])
f = np.array([13755, 13513, 12987, 11600, 8554, 4873, 1955, 734, 265, 120, 70,␣
 ↪54, 48])

# Fit becomes better when we remove the outer points
R = R[1:-1]
f = f[1:-1]

# Plot
R_log = np.log10(R)
f_log = np.log10(f)
plt.plot(f_log, R_log, 'x-')
plt.xlabel('log10 frequency [Hz]')
plt.ylabel('log10 resistance [Ohm]')
plt.grid()
plt.show()
```



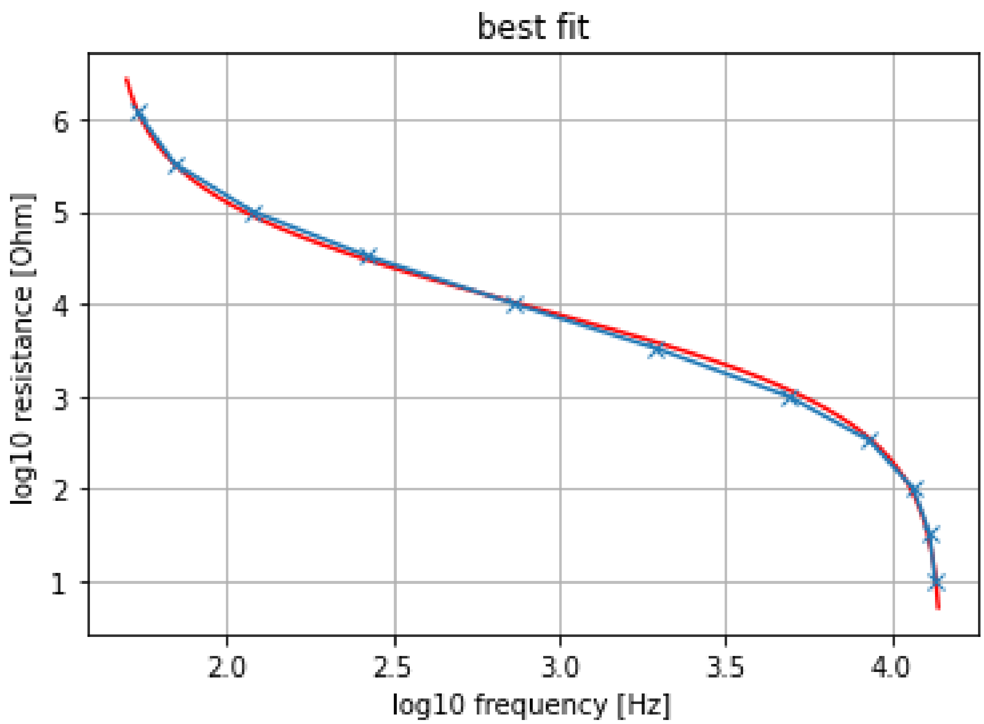
[2]:
```python
def logit_fun(x, k, x0, b, a):
    # The log10(frequency)-log10(resistance) curve can be captured by
    # a `logit()` function, where
    # logit(p) = ln(p / (1 - p)), for 0 < p < 1
    p = (x - x0) * b
    p = list(map(lambda x: np.nan if ((x <= 0) or (x >= 1)) else x, p))
    p = np.array(p)
    return (k * np.log(p / (1 - p)) + a)

# Manually search for a reasonable fit to act as an initial guess
# for the upcoming non-linear least-squares fitting procedure
p0 = [-0.7, 1.68, 0.4, 4]  # Initial guess
x = np.linspace(1.7, 4.14, 501)
y = logit_fun(x, *p0)

plt.plot(x, y, 'r')
plt.plot(f_log, R_log, 'x-')
plt.title('initial guess')
plt.xlabel('log10 frequency [Hz]')
plt.ylabel('log10 resistance [Ohm]')
plt.grid()
plt.show()
```



[3]:
```python
# Non-linear least-squares fitting
from scipy.optimize import curve_fit
popt, pcov = curve_fit(logit_fun, f_log, R_log, p0, method='lm')
print(popt)  # Optimal best-fit result: [k, x0, b, a]
```

```
[-0.61404261  1.65479988  0.40044114  3.97842502]
```

[4]:
```python
y_fit = logit_fun(x, *popt)
plt.plot(x, y_fit, 'r')
plt.plot(f_log, R_log, 'x-')
plt.title('best fit')
plt.xlabel('log10 frequency [Hz]')
plt.ylabel('log10 resistance [Ohm]')
plt.grid()
plt.show()
```



[5]:
```python
# Show fitting residuals and deviation
R_fit = 10**(logit_fun(f_log, *popt))
R_residuals = R_fit - R

print("%8s%12s%12s%10s%9s" % ("f [Hz]", "R [Ω]", "R_fit [Ω]", "res [Ω]", "dev␣
 ↪[%]"))
for idx, value in enumerate(R_fit):
```

```
    print("%8.0f%12.0f%12.0f%10.0f%9.0f" % (f[idx], R[idx], R_fit[idx],␣
↪R_residuals[idx], R_residuals[idx]/R[idx]*100))
```

```
  f [Hz]        R [Ω]    R_fit [Ω]    res [Ω]   dev [%]
   13513           10           11         1        14
   12987           33           27        -6       -19
   11600          100           88       -12       -12
    8554          330          349        19         6
    4873         1000         1179       179        18
    1955         3300         3838       538        16
     734        10000        10364       364         4
     265        33000        29943     -3057        -9
     120       100000        89605    -10395       -10
      70       330000       323978     -6022        -2
      54      1200000      1232152     32152         3
```

[ ]: