Minimalistic bem code for plane wave scattering from soft targets

MM 3.8.2025

mm-bem contains collection of several source codes for calculating scattering pattern obtained when plane wave scatters from soft targets. It uses boundary element method with piecewise constant discontinuous finite elements in 3D (P0).

Calling convension depends on the code language but usually it uses four parameters:

1. mesh file name in msh ascii 2.2 format (defaults to sphere-1.905-600.msh representing 1.905cm radius sphere defined with 600 points and 1196 triangles)
2. direction angle (defaults to θ = 0 what means that it travels along x axis)
3. frequency (defaults to f = 38kHz)
4. sound speed (defaults c = 1480m/s)

The most often results are printed into standard output in the form of two-column data containing:

1. scattering angle in degrees
2. absolute value of scattering length.

This output data could be redirected to txt file or piped to plotting software. The polar scattering strength in logarithmic domain could be obtained by gnuplot polar.gp script. The target strength is the value calculated at 180° distance from wave direction angle.

The source codes are in C, Python, Matlab, Julia and FreeFem. The theoretical calculations for a soft sphere are in Gnuplot. The example results are for 38kHz. The usege of source codes requires installating its evironments or comilers. Only FreeFem version uses Hmatrix approach that allows for faster calculations for large meshes.

The package contains also the demonstration page that do not need any addition installation. The page allows generating sphere, spheroid or ellipsoid meshes and calculating scattering pattern for them. Moreover, it can present the results in polar form of calculated data along with other data file that could be added for comparison. This version can work rather with only medium size meshes!

Shell script

The run.sh script shows software versions used and calling examples generating results for 38kHz (default frequency) on MacBookPro M1 2021 Sequoia 15.5.

```
bash-3.2$ ./run.sh
#!/bin/bash -v

gcc --version
Apple clang version 17.0.0 (clang-1700.0.13.5)
Target: arm64-apple-darwin24.5.0
Thread model: posix
InstalledDir: /Library/Developer/CommandLineTools/usr/bin
julia --version
julia version 1.10.7
python3 --version
Python 3.13.3
freefem++-mpi
freefem++-mpi - version 4.15 (Fri May  2 13:38:38 CEST 2025 - git v4
License: LGPL 3+ (https://www.gnu.org/licenses/lgpl-3.0.en.html)
...

gnuplot --version
gnuplot 6.0 patchlevel 2

gcc src/soft.c -O3 -ffast-math -o bin/soft
time ./bin/soft msh/sphere-1.905-600.msh > out/sphere-1.905-0-38-148

real    0m0.658s
user    0m0.498s
sys 0m0.005s
time julia src/soft.jl msh/sphere-1.905-600.msh > out/sphere-1.905-0

real    0m1.881s
user    0m2.933s
sys 0m1.405s
time python3 src/soft.py msh/sphere-1.905-600.msh > out/sphere-1.905

real    0m4.663s
user    0m4.461s
sys 0m0.078s
time freefem++-mpi -v 0 -f src/soft.edp > out/sphere-1.905-0-38-1480

real    0m6.452s
user    0m6.379s
sys 0m0.044s
time gnuplot -c src/soft.gp > out/sphere-1.905-0-38-1480-gp.txt
```

```
43
44 real    0m0.061s
45 user    0m0.044s
46 sys 0m0.007s
47
48 cd out
49 gnuplot -p -c ../bin/polar.gp sphere-1.905-0-38-1480*.txt
50 qt.qpa.fonts: Populating font family aliases took 56 ms. Replace use
51 mv polar.svg ../figs/sphere-1.905-0-38-1480.svg
52 mv polar.pdf ../figs/sphere-1.905-0-38-1480.pdf
53
54 gnuplot -p -c ../bin/polar.gp YFT*.txt
55 qt.qpa.fonts: Populating font family aliases took 58 ms. Replace use
56 mv polar.svg ../figs/YFT-0-38-1480.svg
57 mv polar.pdf ../figs/YFT-0-38-1480.pdf
58 cd ..
59 bash-3.2$
```

Note

For larger meshes Hmatrix based calculations is the requirement. Note the time of execution for YFT_swimbladder_origin.msh having 7502 mesh points for plain C version with gauessian elimination and FreeFem version with Hmatrix representation:

```
1  bash-3.2$ time ./bin/soft msh/YFT_swimbladder_origin.msh > out/YFT_s
2
3  real    15m17.280s
4  user    15m3.151s
5  sys 0m9.557s
6  bash-3.2$ time freefem++-mpi -v 0 -ng -f src/soft.edp -fm msh/YFT_sw
7
8  real    1m51.404s
9  user    1m50.658s
10 sys 0m0.735s
11 bash-3.2$
```

Examples

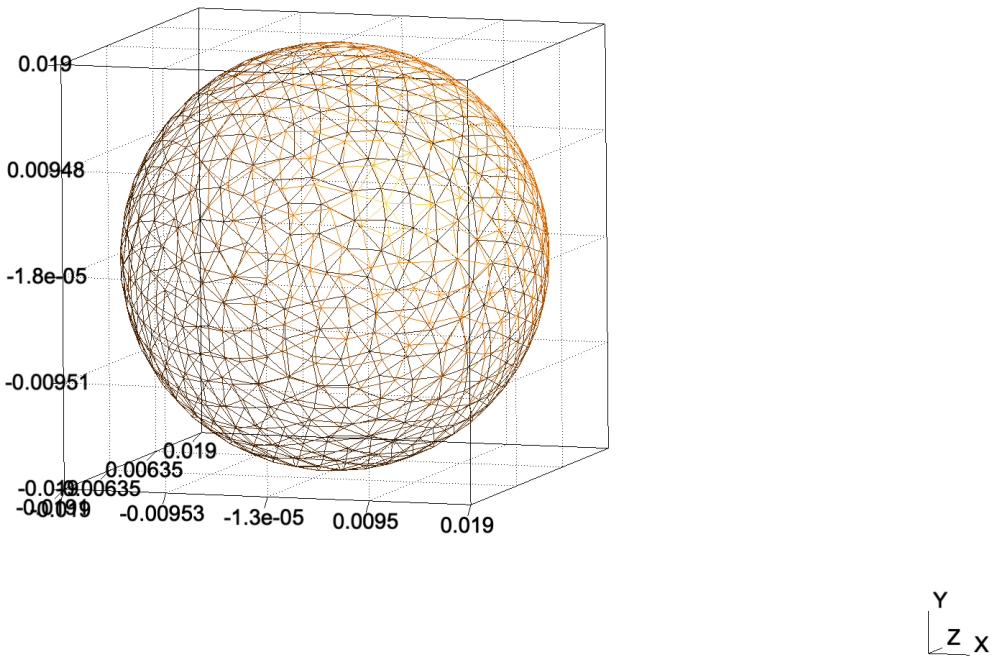

Fig. 1. The sphere mesh with radius of $a = 1.905$ cm having 600 nodes and 1196 triangular elements used for verification.

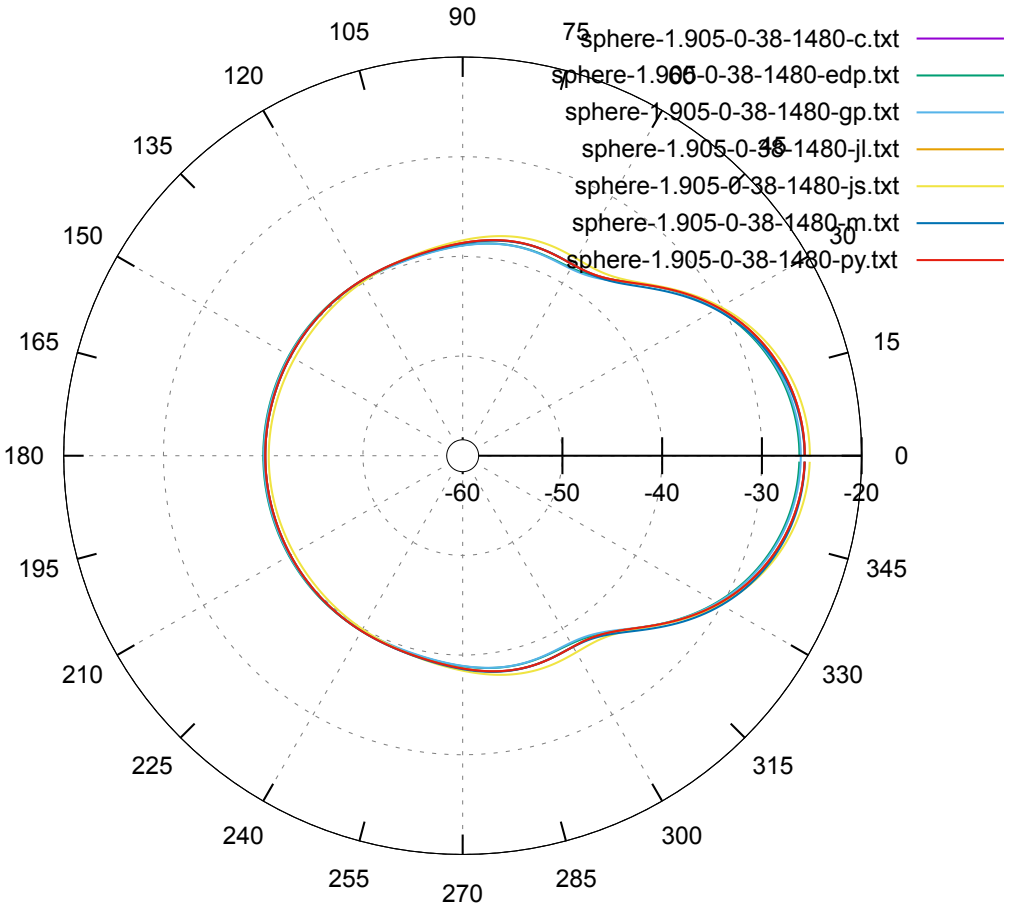

Fig. 2. The results obtained with codes written in several languages for soft sphere with radius of $a = 1.905$ cm in salt water $c_0 = 1480$ m/s at 38kHz.

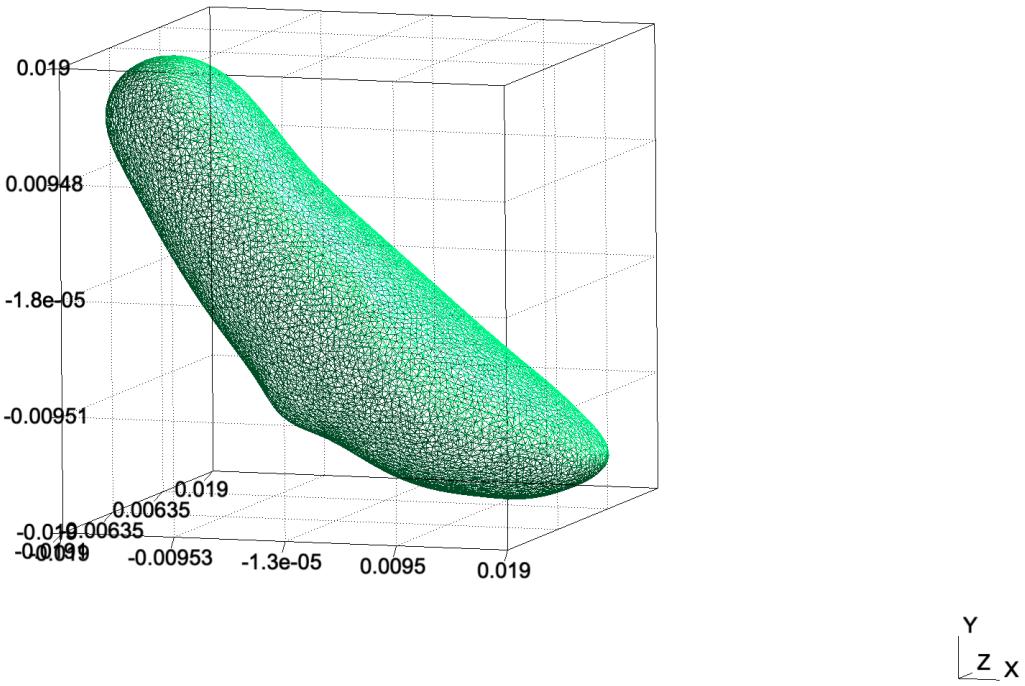

Fig. 3. The Yellow Fin Tuna swimbladder having 7502 nodes and 15000 triangular elements.

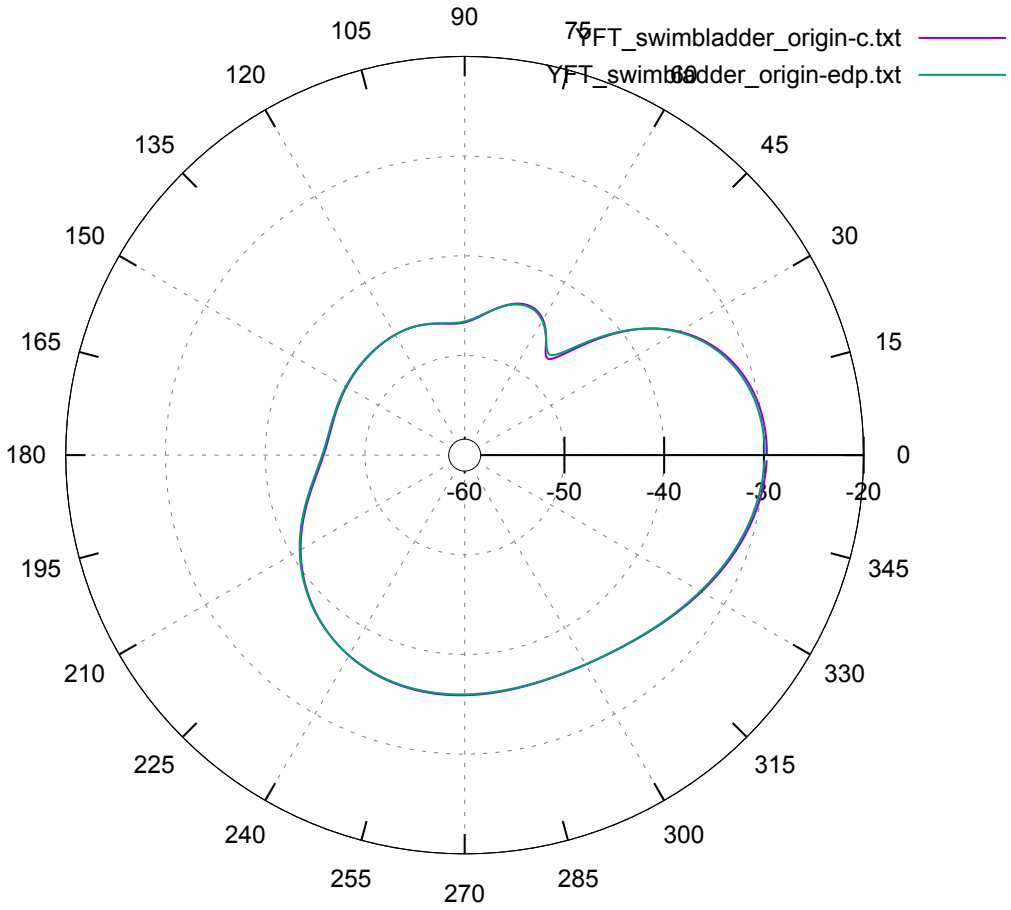

Fig. 4. The results for vacuum filled YFT swimbladder in salt water $c_0 = 1480$ m/s at 38kHz.

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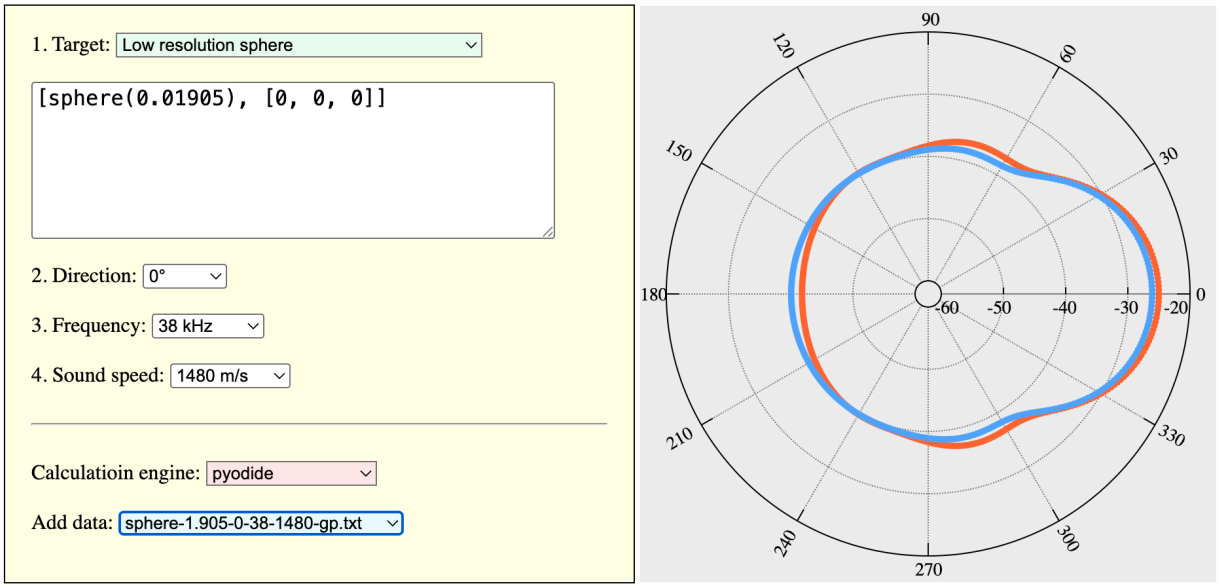

Fig. 5. The screendump from mm-bem web-page for low resolution mesh of 1.905 cm radius sphere along with theoretical curve for soft sphere in salt water $c_0 = 1480$ m/s at 38kHz.