

Matlab-Envelope (MENV) Documentation

KIERSTEN RUISARD

May 31, 2018

Contents

1	Introduction	2
2	Envelope integrator	2
3	Running MENV from the GUI	2
3.0.1	Defining and solving a lattice	2
3.0.2	Optimization in the GUI	6
3.0.3	Side note on parallel instances	7
4	Organization of MENV	8
4.1	Main MENV routines	8
4.2	GUI code	8
4.3	Additional (untested) routines	9
5	MENV from the command line	10

1 Introduction

MENV can be run from the command line ("clmenv.m") or GUI ("menv.m"). The GUI and original MENV functions were written by Hui Li. Kiersten added the command line functionality, and copied over much of Hui Li's original code into `clmenv`.

2 Envelope integrator

MENV integrates the KV envelope equations in X and Y:

$$X'' = -K_X X - \frac{2K}{X+Y} + \frac{E_X^2}{X^3} \quad (1)$$

The integration is handled in the Matlab function "menv_integrator," which integrates through a specified beam-line given focusing gradients. The integration uses the leap-frog method. The two sub-functions which form each integration step are given below:

```
1 function [x2,y2,xp2,yp2,d2,dp2] = step(x1,y1,xp1,yp1,d1,dp1)
2 % function for single step
3 x2 = x1+xp1*ds;
4 y2 = y1+yp1*ds;
5 d2 = d1+dp1*ds;
6 [xpp,ypp,dpp] = calc_prim2(x2,y2,d2);
7 xp2 = xp1+xpp*ds;
8 yp2 = yp1+ypp*ds;
9 dp2 = dp1+dpp*ds;
10 end

1 function [xpp1,ypp1,dpp1] = calc_prim2(x1,y1,d1)
2 % function to calculate velocity impulse
3 % Reiser eq. 4.191, 4.192
4 xpp1 = -( kx*x1-2*K/(x1+y1)-Ex^2/(x1^3) );
5 ypp1 = -( ky*y1-2*K/(x1+y1)-Ey^2/(y1^3) );
6 dpp1 = irho - kx*d1;
7 end
```

3 Running MENV from the GUI

The GUI can be launched by executing the command `menv` from the Matlab command line. Prior to running MENV, make sure that all files in the MENV directory are in the Matlab path (run `setpath` from the command line). This will launch a GUI window as shown in Fig. 1.

3.0.1 Defining and solving a lattice

Elements can be added using the "Insert" button, through a GUI interface shown in Fig. 2. Beam parameters (including initial conditions, emittance and perveance) are defined using the "Beam Parameters" option in the "Solve" drop-down menu. This launches the GUI shown in Fig. 3. Alternatively, run-files with .spt extension can be loaded using the command "Open" in the drop-down menu (or Ctrl-O).

Once beam and lattice parameters are defined, you can solve the envelope equations by hitting the solve button (green exclamation mark) or selecting "Compute Solution" from the "Solve" menu. To draw a schematic of the lattice elements, press the "draw" button. Figure 4 shows the solution for a 0.7 mA beam in a FODO lattice defined in the example file "FODO_0_7mA_dipl.spt."

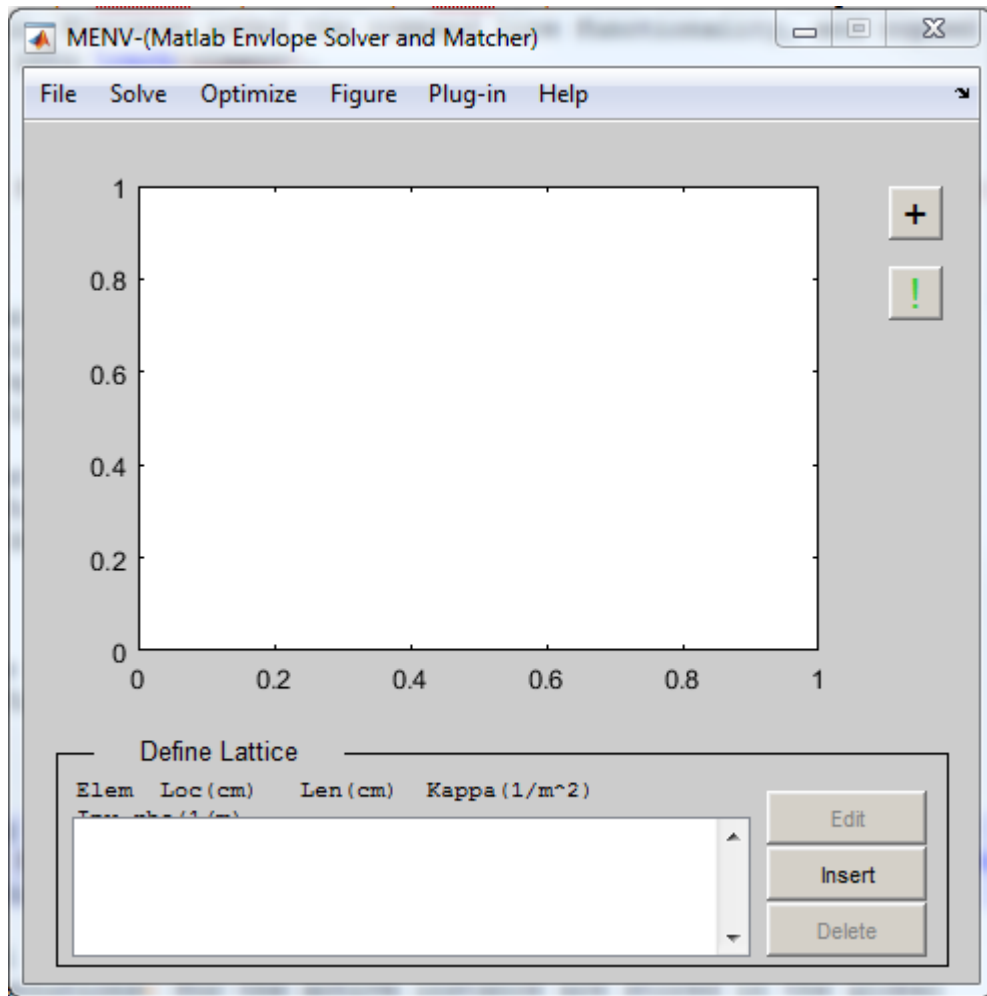


Figure 1: Main GUI window as it appears after launching MENV.

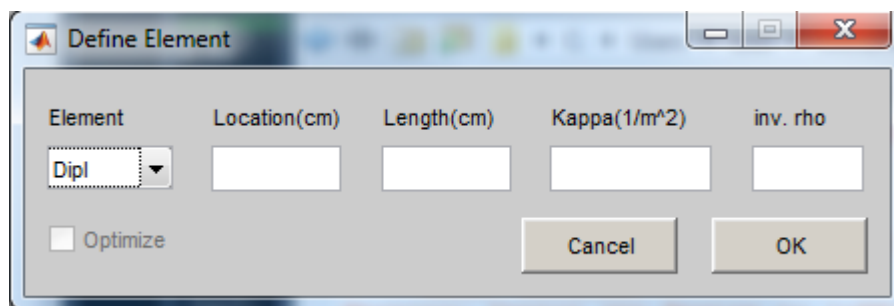


Figure 2: GUI window for inserting new elements.

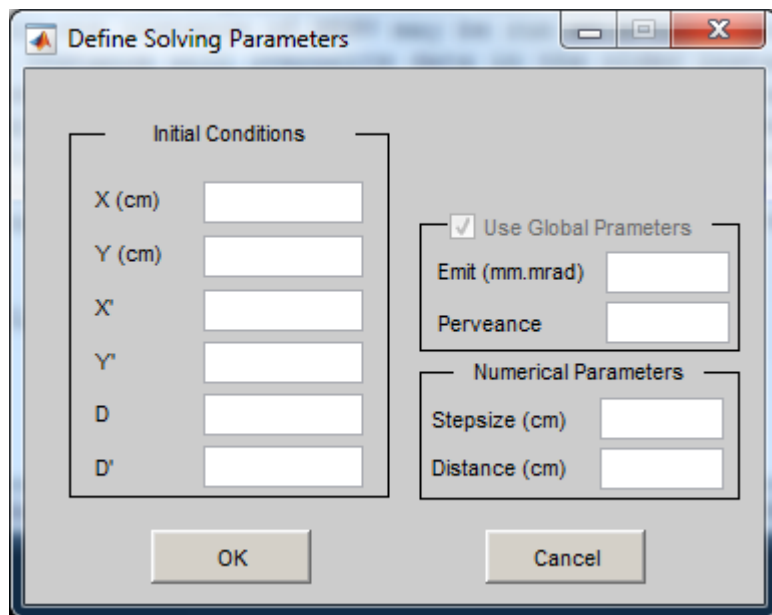


Figure 3: GUI window for defining beam parameters.

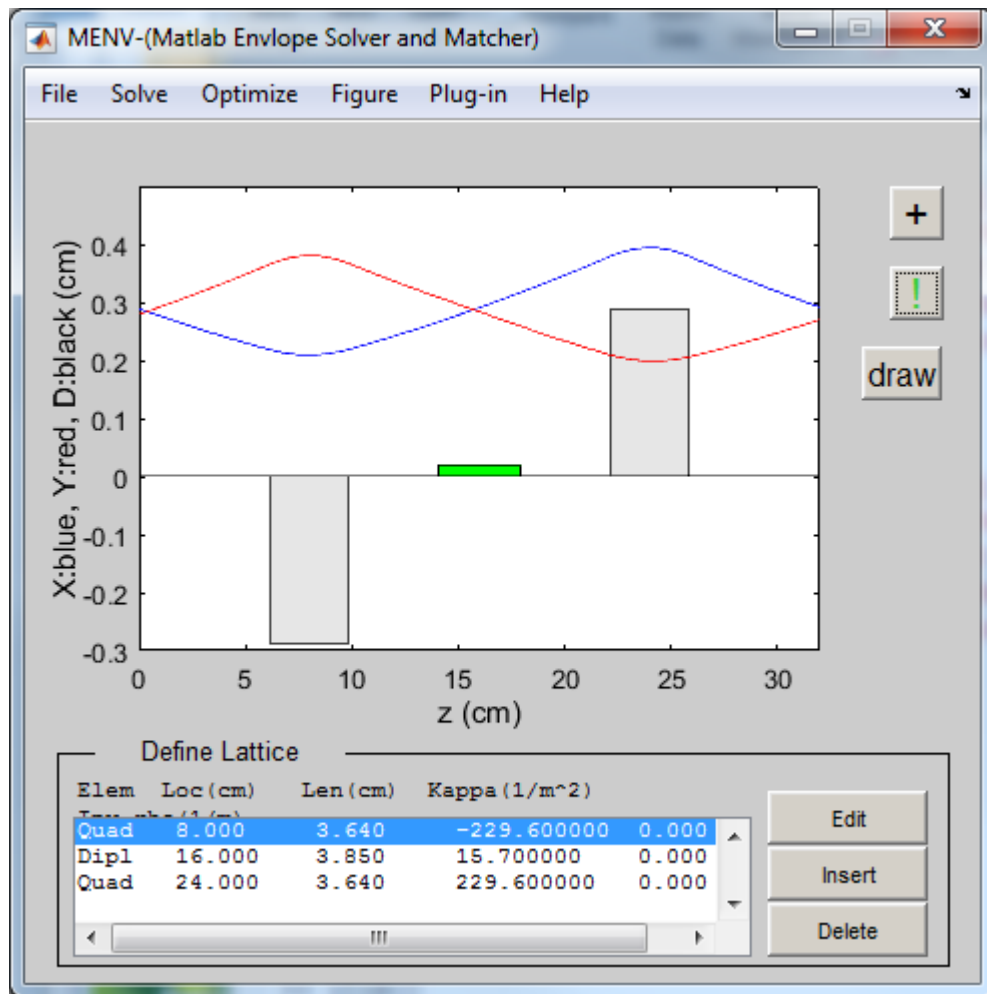


Figure 4: FODO lattice solution from example file "FODO_0_7mA_dipl.spt."

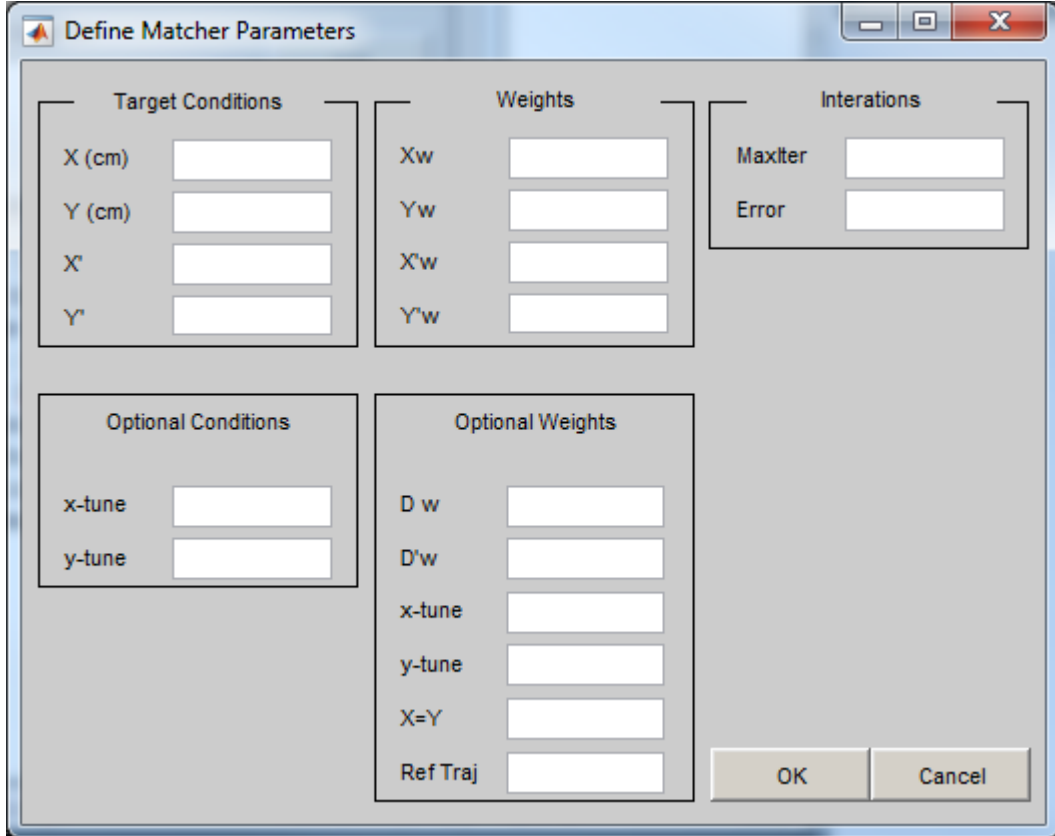


Figure 5: GUI window for defining parameters for matching/optimization routines.

3.0.2 Optimization in the GUI

MENV allows for two kinds of optimization: optimizing over initial beam conditions to find the periodic solution and optimizing quadrupole/solenoid strengths to meet a target condition. Before running a matching routine, you must define targets and weights by selecting "Matcher Parameters" under "Optimize." The GUI that is launched is shown in Fig. 5. If you are optimizing for the periodic solution, only the weights need to be defined. If you are optimizing to a target, targets must be defined as well. Targets and weights for X, Y, X', Y' at the end of the transport line must always be defined.

There are additional targets and weights that *may* be defined as desired; if not defined they will be set to a default value of 0. Optional targets include desired values of X and Y tunes. Optional weights include dispersion (use if you want to also find the periodic solution for dispersion), weights for the tune condition, and weights for global properties of the beam envelope. The global properties include a condition for "roundness" $X=Y$, which is defined as the rms value of $x(s)-y(s)$ along the beam-line. The **Ref Traj** condition tries to match the envelope to a reference trajectory (inspired by the SPOT code, on which MENV is based [Allen, C. K., Guharay, S. K., & Reiser, M. (1998). Optimal Transport of low Energy Particle Beams. Epac, (3), 2324–2326.]). The reference trajectory is defined either by loading a text file in which a curve is defined as series of points in $X-Z$ ("Plug-in," "Reference Trajectory," "Load") or by drawing in the MENV window ("Plug-in," "Reference Trajectory," "Draw").

3.0.3 Side note on parallel instances

The data (parameters, settings and solutions) for the active instance are stored in the global object `guim`. As this is a global variable that does not have a unique name for each instance of MENV, only one instance of MENV may be run at a time (you can launch two, but data from the most recent instance will overwrite data in the older instance). If you want to run parallel MENV instances, you need to run separate Matlab instances as well. This could be resolved by attaching data to the GUI window rather than a global variable, and this was the case in the older (Hui Li) version of MENV. The choice was made to adopt a global variable to allow use of functions written in the "command-line" MENV class `clmenv` from within the GUI (instead of having separate functions for command-line and GUI versions).

4 Organization of MENV

4.1 Main MENV routines

The two MENV interfaces (GUI or command-line) draw on the same set of functions to perform envelope integration and optimization. Table 1 describes the functions which make up the heart of the MENV code. All of these are found in the folder “menv-main/.”

Table 1: MENV functions

Name	Purpose
clmenv	Class used to run command-line and GUI menv. Contains many useful routines to load, organize and store simulation data and parameters.
runmenv	Function which runs MENV integrator and returns solution data as a function of s. Sub-routine for “Solve” method in clmenv and GUI.
menv_makekappaarray	Translates lattice definition into κ -array used in integrator Returns strength vector for optimizable elements Sub-routine for runmenv function
menv_updatekappaarray	Updates κ -array based on changes to optimizable elements Returns new strength vector for optimizable elements Sub-routine for optfunc function
menv_integrator	Lower-level function to perform integration through defined beamline
match2period	Function to optimize initial beam conditions for periodic matched solution Sub-routine for “Periodic Matcher” method in clmenv and GUI.
match2target	Function to optimize focusing elements to meet specified target Sub-routine for “Target Matcher” method in clmenv and GUI.
optfunc	Function used in each optimization step in “match2target” Input: strength of optimizable focusing elements Output: weighted cost-function vector
periodfunc	Function used in each optimization step in “match2period” Input: initial conditions X,X',Y,Y',D,D' Output: weighted cost-function vector

4.2 GUI code

The dependencies of the GUI **menv** are listed below. All GUI-specific files are stored in the folder “menv-gui/.”

- `menv.m` :: Code for creating main GUI window
- `defElement.m` :: Code for creating element insert/edit GUI window
- `defParam.m` :: Code for creating beam parameter GUI window
- `defMatcher.m` :: Code for creating matcher parameter GUI window
- `ImportOpt.m` ::
- `prepareMenu.m` :: Code for creating menus on main GUI window
- `menvEvent.m` :: Contains code for interpreting commands sent by the GUI window
- `clmenv.m` :: Contains many of the upper level routines, called by some of the commands in `menvEvent.m`

It should be noted that GUI MENV was written following (presumably) older Matlab guidelines in which GUI data is stored in a `.mat` file as opposed to a `.fig` file.

4.3 Additional (untested) routines

I wrote additional optimization routines to try to solve more sophisticated problems. These have not been vetted as thoroughly and should be closely scrutinized before use. To indicate this, they are stored in the folder “beta/” in the MENV directory. There may be some bugs due to changes to the main MENV routines/structure that were not filtered through to these functions. Matlab has a huge library of optimization algorithms, these can be added modularly to expand MENV capabilities in a similar fashion as seen here.

Table 2: “beta” MENV functions

Name	Purpose
GSmatch2target	Function to optimize focusing elements to meet specified target using Matlab “Global Search” algorithm. Sub-routine for “Global Search” method in <code>clmenv</code> and GUI.
MOmatching	Function to optimize focusing elements to meet specified target using a Multi-Objective algorithm. Sub-routine for “Multi-Objective” method in <code>clmenv</code> and GUI.
svoptfunc	Function used in each optimization step in “GSmatch2target” Calls “optfunc” but returns cost function as single-vector rms quantity
stepfuncMO	Function used in each optimization step in “MOmatcher”

Also in the “beta/” folder, I include routines “skewstep.m” and “skew_test.m.” Apparently at some point there was an attempt to include skew-coupling terms in the envelope integration. I cannot speak to the accuracy or robustness of this code, but I preserve it in case it is ever pursued again.

5 MENV from the command line

A simple example, in which a .spt file is loaded into MENV and run from the command line (modified from run_clemnvn.m):

```
1 % — initiate clmenv instance
2 clm = clmenv();
3
4 % — load .spt file
5 sptfilename = which('FODO_0_7mA_dipl.spt');
6 clm.open(sptfilename)
7
8 % — solve
9 clm.solve()
10
11 % — find periodic solution
12 clm.periodicmatcher()
```

A slightly more complex example, in which a lattice is constructed in MENV from the command line (modified from run_clemnvn_inj.m):

```
1 clm = clmenv();
2
3 % — set params
4
5 % Beam parameters
6 emittance = 30; % mm-mrad
7 perveance = 0.0001045;
8 x0 = .3; % cm
9 y0 = .3; % cm
10 xp0 = 0.0;
11 yp0 = 0.0;
12
13 % Simulation parameters
14 stepsize = 0.005; % cm
15 distance = 32; % cm
16
17 % optimization parameters
18 iterations = 20;
19 tolerance = 1e-6;
20
21 % — Lattice description
22 elements = 'QDQ'; % element types
23 location = [8,16,24]; % element location
24 lengths = [3.6400,3.8500,3.6400]; % element length
25 str = [220,15.7000,-220]; % quadrupole strength (kappa)
26 bend_ang = [0 10 0]*pi/180; % bend angle
27 invrho = bend_ang./lengths; % inverse rho
28 opt = [0,0,0];
29
30 % — assign params to menv structures
31 clm.maketarget([1,1,1,1],[1,1,1,1])
32 clm.makeoptiset(iterations,tolerance) % Makes file optiset
33 clm.defmatcher() % loads matcher settings
34
35 ic = struct();
36 ic.x0 = x0; ic.y0=y0; ic.xp0=xp0; ic.yp0=yp0; ic.D0 = 0; ic.Dp0 = 0;
37 clm.makeparams(emittance,perveance,ic,stepsize,distance) % makes param file
38 clm.defparam() % loads params
```

```
39
40 clm.deflattice(elements,location,lengths,str,opt,invrho) % loads lattice
41
42 % -- look at initial solution
43 clm.solve()
44
45 % -- solve for periodic solution
46 clm.periodicmatcher()
```