Cart-Ball User's Guide

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Abstract

This document is a user manual for the Pendulum simulation software used in an Internet course on fuzzy control, taught at the Technical University of Denmark. It contains installation instructions, a brief description of the software, and how to use it.

Contents

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Tech. Report no 98-E-865 (usrguide), January 25, 1999

1. Introduction

The problem simulated by the software is an inverted pendulum. In this case the inverted pendulum is implemented by placing a ball on a curved surface. The curved surface (a bridge) is part of a moving cart and the objective of the controller is to move the cart in a manner such that the ball is balanced on top of the bridge, and at the same time place the cart at a predetermined location.

2. Installation

The simulator is shipped as a compressed archive. To install it, you need to uncompress (unzip) the archive using any software that can handle standard .ZIP files.

PC To install the simulator, unzip the pendulum package into any directory. Programs to unzip are for example **PKUNZIP** and **WINZIP**. Start up Matlab and change into the directory where the software is located.

² To start the simulator, type `pendulum`

UNIX Installation is similar to the PC installation. The software should be unzipped into any directory (any directory in your home directory will do). Most UNIX environments have an `unzip` command that can uncompress normal .zip archives. If you do not have a program that can unzip the archive, contact your system administrator and ask him/her to install it. If you upload (ftp) the programs to a UNIX machine, be sure to upload the *.mat files as *binary* files, and all other files as *text* files. Also make sure that all file names on the target system are in *lower case* letters (your `unzip` command may have an option that does this for you).

Start up Matlab and change into the directory where the software was placed.

² To start the simulator, type `pendulum`

The Pendulum simulator can be placed in any directory but for the software to work, it *must* be started from the directory where the software is. If you want to use the Pendulum program in a multi-user environment, but you only want to have one installation, install the program as usual. You will then have to add the Pendulum directory to the default Matlab search path (or instructing the user to do so each time). Each user then has to copy all .txt and .mat files from the Pendulum directory to his /her own pendulum directory. By starting the program from that directory, each user will have their own individual settings.

3. Program overview

The simulator is menu driven. All parts of the program can be reached via the menus although some shortcuts have been provided on the user interface. There are five items on the menu:

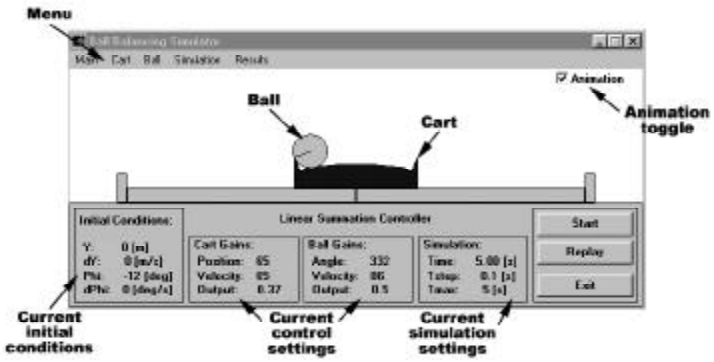

Figure 1: Main window of the Pendulum simulator.

3.1 Main window

Main Access to loading and saving of settings.

Cart The cart controller can be accessed here. Anything changed under this menu item affects ONLY the cart controller and not the ball controller.

Ball Settings for the ball controller. As before, changes made here affect only the ball controller and not the cart controller.

Simulation Changes to the simulation itself. Changes made here will affect the whole simulation. Options include for example the type of controller used, simulation period and the step size in the simulation.

Results Once the simulation has been run once, you can plot the results from here.

3.2 Shortcuts

Buttons There are three buttons on the interface: Start will start a new simulation, Replay will replay (reanimate) the last simulation, and Exit will quit the program.

Animation checkbox The animation of the cart and ball can be turned off by unckecking the animation toggle. This will speed up the simulation dramatically for those that only want the results.

Mouse clicking On the Win95 platform, it is possible to click on any of the settings. This will bring up a dialog box to edit tat particular setting. This does not work on a UNIX platform or on WinNT.

3.3 Changing the controller parameters

There are two controllers in the simulator, one for the ball and one for the cart. These controllers are completely independent so changing the setting in one will not affect the setting in the other. The parameters that can be changed are:

- Gains
- Fuzzy sets
- Rule base

3.4 Changing the Fuzzy sets

The membership functions used in the Pendulum simulator can be changed through a special interface. Figure 2 shows how the editing window looks.

The plot in the window shows only one linguistic variable at a time, and as each variable has three terms defined there are three lines on the plot. Only one fuzzy set can be changed at a time though.

Six points define each fuzzy set, but only four can be changed by the user. Furthermore,

only the x-coordinate can be changed but the y-coordinate is fixed. Thus each set is defined as,

```
X = [-100, LeftBreakpoint, LeftShoulderPoint,
     RightShoulderPoint, RightBreakpoint, 100]
Y = [0, 0, 1, 1, 0, 0]
```

The membership functions are found by drawing lines between the respective breakpoints and shoulder-points and then always using the one that is lower at any particular place. If the membership functions are non-linear (cosine), *s-curves* and *z-curves* are drawn between the respective points instead of lines. The membership functions are built using the Matlab function files picurve.m, scurve.m and zcurve.m if you want to see how the exact process is.

There are two shortcuts provided to change the membership functions:

- *Mouse Input.* Allows placement of current point (x-coordinate) with the mouse.
- *Mirror LR.* Mirrors membership functions (left to right). This will make the right membership function (**ISR**, **MVR**, **PSR**, **PHR**) mirror the left membership functions (**ISL**, **MVL**, **PSL**, **PHL**) respectively.

3.5 Changing the Rule Base

The simulator supports up to 9 rules (Fig. 3). In the rule base dialog the initial nine rules are listed. The rules can be selected and changed with the drop-down menus at the bottom of the dialog and particular rules can be disabled by removing the toggle in the respective checkbox.

4. Hints

The animation of the cart and ball slows the simulation dramatically. By turning off the animation, you can get the results of the simulation much faster. This can be very handy when the controllers are being tuned and you only want to see the plots. If the plots seem strange, the animation can always be viewed later by hitting the Replay button.

Solutions to Matlab problems might be found using Mathworks' solution search engine at

http://www.mathworks.com/support/solutions/

4.1 Known problems and bugs

1. *Division by zero when changing rules or sets.* The rule base is incomplete. The simulation results will not be correct if the incomplete part of the rule base is used.
2. *Can't find some files.* Start the pendulum program in the pendulum directory.
3. *Invalid object handle.* If more than one editbox is opened at once there will be problems

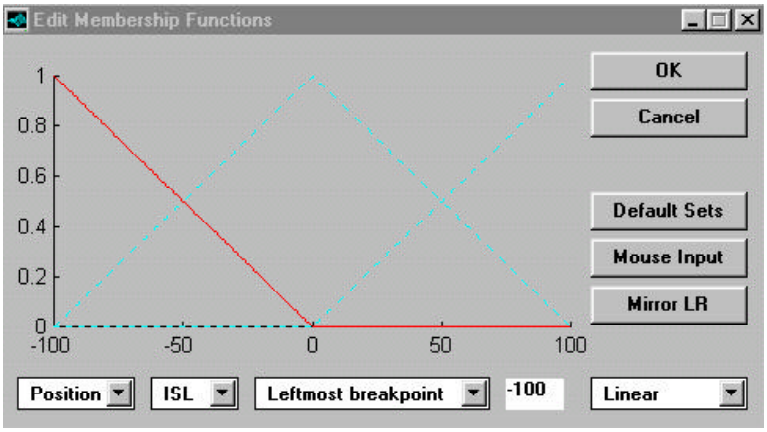

Figure 2: Edit membership functions window.

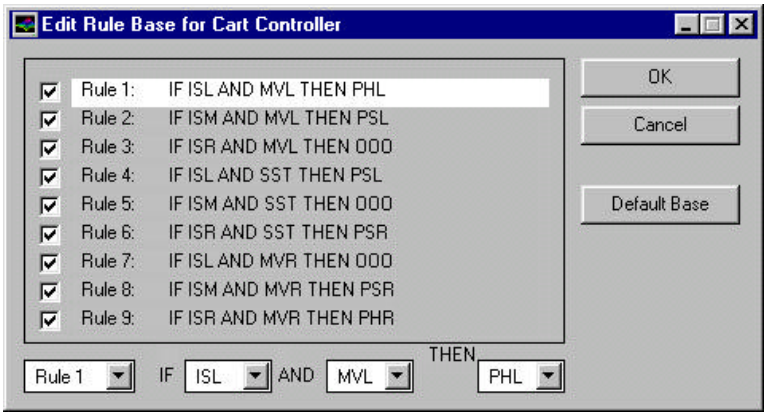

Figure 3: Edit rule base window.

4. *Impossible to stop simulation if animation is off*. This is bothersome.
5. *The animation disappears*. This happens for unknown reasons and is a bug in Matlab according to Mathworks.
6. *Velocity is not zero at end-stop*. When the cart hits the end-stop, the position is constant, but the velocity is not zero.
7. *Edits wrong membership function*. Select, say, **ISM** instead of **ISL** and then change to **Velocity** instead of **Position**, it says **SST**, but **MVL** is the one that gets changed.
8. *Edit sets*. While changing the sets I sometimes get the error that the command empty is not used properly. If you get something like this:

```
Warning: Divide by zero.
In d:\jan\matlab\pendul3\CARTBASE.M at line 89
In d:\jan\matlab\pendul3\CARTTABL.M at line 18
In d:\jan\matlab\pendul3\DOEVENT.M at line 301

Warning: Future versions will return empty for empty ==
scalar comparisons.
```

   - it is because there is one point (zero) where the rule base is undefined. The 'division by zero' occurs when Pendulum tries to compile the lookup table. It will disappear when you make sure the ISL and ISR together cover the whole range of the universe (a similar remark applies to MVL and MVR). The last warning is a bit irritating.
9. *Edit membership functions*. I found a software bug related to membership edition: An error occurs when you try to edit ISM or ISR parameters without edit ISL-Leftmost breakpoint first (error while evaluating callback string).
   I think the origin of the problem is incomplete rule bases. If you, for example, in ISR change the Right Shoulder Point parameter to 90 (starting from the default settings), then you get a window telling you the rule base is incomplete. After that, the editing window is abnormal. This also happens if you in ISL change the Left Shoulder Point to -90. The incomplete rule base also results in a 'divide by zero' warning, which is to be expected, and sometimes the side errors

```
??? Index exceeds matrix dimensions.
??? Error while evaluating callback string.
```

   Pendulum ought to be able to handle the incomplete rule base, and I will try to correct it.
10. *Changing step size gives an error*. In the new version we obtained it is not possible to change the stepsize. Matlab gives the following error.

```
> ??? Error using ==> str2num
> Requires string or character array input.
>
> ??? Error while evaluating uicontrol Callback.
```

There are two ways to input numbers, in principle. You can either click on the number itself (does not work under Win NT and Unix), or go to the drop down menu on the top bar.

Brenda: I did not have this problem. Maybe it is the Matlab version? (I use version 5.2.0.3084).

The particular combination of Matlab and Windows versions are suspected.

11. *Matlab crashes when you try to change a gain*. This happens on certain combinations of Matlab and Windows versions. With the same Matlab version it happened on some PCs, but not others. The bug may thus be in Windows. Only suggestion is to download and install the latest Service Release to your Windows system from the MicroSoft home page.
12. *GUI problems with Matlab 5 under Win98*. Earlier versions of MATLAB (before 5.2.1) are not supported under Windows 98. The Student Version of MATLAB has been tested and appears to work properly under Windows 98, see Mathworks expanation, solution number 20744, at

    http://www.mathworks.com/support/solutions/v5/20744.shtml

    Check also the folllowing solution concerning problems with launching Student Edition,

    http://www.mathworks.com/support/solutions/v5/8831.shtml
13. *Nonlinear control surface seems to have no effect*. The linear summation controller is implemented as

    $$U = (g1 * Y + g2 * dY) * u1 + (g3 * Phi + g4 * dPhi) * u2$$

    It does not use the control surface. When you switch to rule based or table based control, then Pendulum uses the surface. Perhaps changing the name of the menu item from "Plot control surface" to "Plot FUZZY controller control surface" would help.
14. *The rule base in incomplete*. When you remove rules, for example rules 2, 4-6, 8, you may get the message 'Rule base is incomplete'. This is a warning that some input combinations are undefined, i.e., not covered by the rule base anymore. If you subsequently try to edit the fuzzy sets, in order to expand their support, you will get error messages in the Matlab command window concerning the GUI callback mechanism. The proper procedure is to change the fuzzy sets before removing rules, such that the rule base is always defined.
15. *Control surface viewpoint*. On the 3D display, it was hard to see the efect of fuzzy set

changes on the surface; allow the display of the surface from 0 or 90 deg horizontal angles (to get a 2D display).

16. *Saturation of inputs*.

> For g3=800 and g4=80, the phase plot showed that Phi*g3 starts at -100
> while the max(g4*dPhi) < 100, therefore Phi was at
> the saturation point while dPhi was still ok. Increasing g3=1000 and
> g4=100 showed that dPhi was now saturated while
> Phi still started at -100. The phase plot shows a graph where both axis
> are kept to [-100,100]. Phi was saturated even at
> g3=80, it is just that the plot started to plot from -100 on.
>
> The interesting fact was that even when both Phi and dPhi clearly
> saturated the controller, the time response plot of the
> fuzzy table controller was identical with the linear controller.

This is strange, because the table based clips inputs
to [-100, 100], after gains, while the linear summation
controller clips Y and Phi only, according to physical
limits. I would have expected different responses.

> I
> assumed that the table controler extrapolates when inputs
> are outside its lookup range,

No, it just limits the inputs.

> so I switch to the rule base controler.
> Again, the inputs should have saturated the controller,
> however the output showed no clipping.

The rule based controller does not clip at [-100, 100],
but the fuzzy sets extend towards infinity, i.e., you get
the same results as in y*g1 = +- 100, g3*Phi = +- 100, etc.