Reinforcement learning based control of an underactuated double pendulum system

Master's Thesis Nr. xxx

Scientific Thesis for Acquiring the Master of Science Degree
at the School of Engineering and Design
of the Technical University of Munich.

Thesis Advisor	Laboratory for Product Development and Lightweight Design Prof. Dr. Markus Zimmermann
Supervisor	Laboratory for Product Development and Lightweight Design Akhil Sathuluri Hans Zweitkorrektor (Second corrector)
Submitted by	Chi Zhang Karl Köglsperger Straße 9, 80939, München Matriculation number: 03735807 chi97.zhang@mytum.de
Submitted on	Garching, 15.11.2023

Declaration

I assure that I have written this work autonomously and with the aid of no other than the sources and additives indicated.

Garching, 15.11.2023

Chi Zhang

Project Definition (1/2)

Initial Situation

Add your Project Brief here. If you don't need it, comment out the creation of this Project Brief in the main document `Thesis.tex`.

Goals

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Project Definition (2/2)

Contents of this Thesis

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Project Note

Master's Thesis	Nr. xxx
Supervisor	Akhil Sathuluri
Partners in industry/research	DFKI GmbH, Robotics Innovation Center
Time period	Starting Date - 15.11.2023

The dissertation project of Akhil Sathuluri set the context for the work presented. My supersivor Akhil Sathuluri mentored me during the compilation of the work and gave continuous input. We exchanged and coordinated approaches and results monthly.

An accurate elaboration, a comprehensible and complete documentation of all steps and applied methods, and a good collaboration with industrial partners are of particular importance.

Publication
I consent to the laboratory and its staff members using content from my thesis for publications, project reports, lectures, seminars, dissertations and postdoctoral lecture qualifications.

The work remains a property of the Laboratory for Product Development and Lightweight Design.

Garching, 15.11.2023

Chi Zhang

Akhil Sathuluri

1 How to use this template

This LaTeX template is adapted from the Word template for student theses at LPL. If you are not sure regarding the formatting, please refer to the Word template or ask your supervisor.

1.1 Setup your editor

This template was created and tested with the TexStudio editor in combination with MikTex, but in general you should be able to use other editors as well.

You should check the following settings and adapt them accordingly if neccessary:

- Standard Compiler: PdfLaTeX
- Standard Bibliography: biber

You can change these default programs in TexStudio by choosing `Options` → `Configure TexStudio` → `Build`.

Also, by default, this template places all graphics and diagrams created with `TikZ` or `pgfplots` in external pdf files. This significantly reduces the compilation effort, especially for extensive theses, but you will need to specify the compiling command as follows:

In Texstudio, choose `Options` → `Configure TexStudio` → `Commands` and add `--enable-write18`[1], so that the command for PdfLaTeX reads

```
pdflatex.exe -synctex=1 -interaction=nonstopmode --enable-
   write18 %.tex
```

[1] Alternatively, you can use `-shell-escape` instead.

1.2 Working with LaTeX

If you are somewhat familiar with LaTeX and are just looking for solutions to specific questions and problems, forums like `https://tex.stackexchange.com/` have proven to be very reliable.

If, on the other hand, this thesis is your introduction to LaTeX, a didactic approach is recommended. There is a lot of literature that will help you to get started, and will remain a helpful tool in your further LaTeX-"career". Representative for many other works (**Schlosser2014**) should be mentioned here.

1.3 Working with this template

As a basic rule: This template has been created to the best of our knowledge and belief, nevertheless minor (and probably major) errors may still be included. If something seems strange or illogical to you, do not hesitate and adapt the template to your needs – preferably in consultation with your supervisor, of course.

You can get an impression of the structure of this template from fig. 1.1. The main folder contains only the `Thesis.tex` file, which combines all your individual files to the thesis. Here you define the meta data, like supervisor, title etc.. Also you include your chapters here – or comment them out using the `\includeonly` command if you want to compile only single chapters at an advanced stage to save time.

The `Settings` folder contains all document definitions. Here you only need to add your task description, otherwise you do not need to change anything. If you feel confident in using LaTeX, you may of course include additional packages or adapt the template to your needs.

In the folder `Chapters` you create a separate .tex file for each chapter and include them – analogous to the two example chapters – in `Thesis.tex`. If you want the main chapters of your thesis to always start on the right-hand side, add the command `\cleardoubleemptypage` to the end of each chapter.

In `Resources` you put all the resources you need to create the thesis with LaTeX. The structure of this folder in detail is up to you.

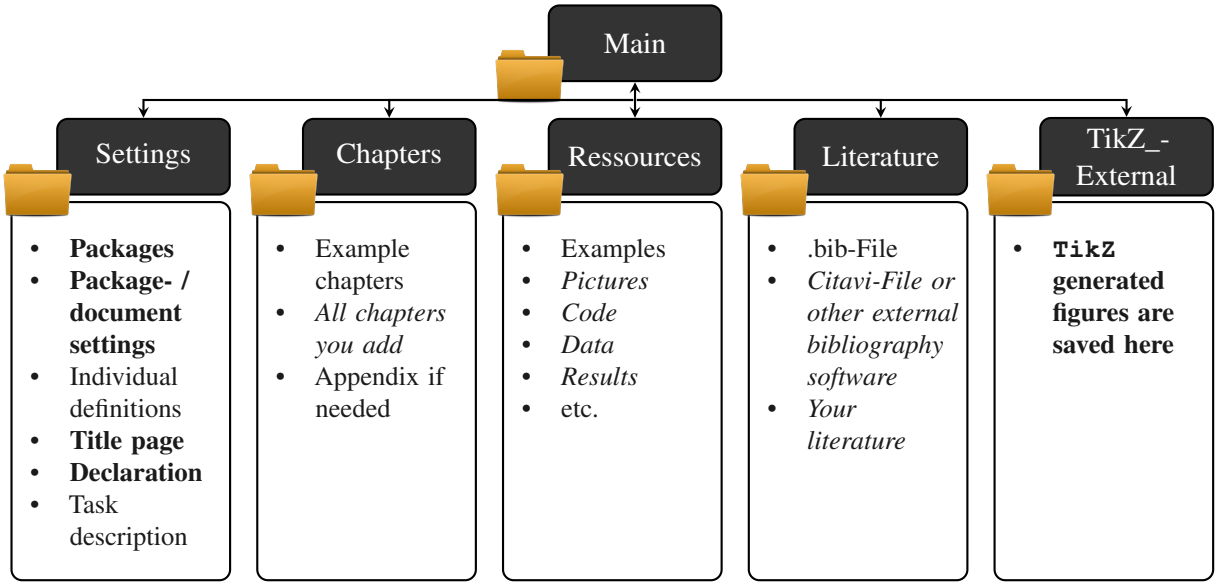

Figure 1.1: Folder and file structure of this LaTeX template. ***Bold typed*** *are elements which are already defined and do not need to be changed by you,* italic font *on the other hand represents elements which you can or should add yourself.*

The folder `Literature` contains at least the .bib file with all entries. If you have this file created externally, for example via Citavi or JabRef, you can of course store this data here as well as all your literature.

It is best not to add anything to the folder `TikZ_External`. All graphics created by `TikZ` are stored here temporarily, so that they can be included during compilation in a time-saving way, unless you have changed them.

And of course, you can customize this structure to your liking.

1.4 Citation

In general, we at the Laboratory of Product Development and Lightweight Design cite according to the guidelines of the TUM citation guide; the author-year nomenclature (APA) suggested there is already integrated in this template.

Additionally at LPL: Both direct and indirect citations should always be accompanied by page references! Only in the exceptional case of a reference to a work as a whole, a page reference can be omitted. Furthermore, if a work is written by three or more authors, only the first one is to be indicated in the text, all others are replaced by *et al.*.

With the implemented style you can, for example, refer to one work (**zimmermann2013vehicle**) elegantly multiple times (**zimmermann2013vehicle**), or cite several sources at once (**zimmermann2013comp**

And you can directly cite **zimmermann2013vehicle** or multiple authors, e.g., **zimmermann2017designSchlo** like this in the body text. Please check the source code for the used commands.

1.5 Printing

This section lists the LPL printing guide:

- Printing is done at LPL. Three copies in total, one for you and two for the lab and supervisor. Any additional copies, such as for industry partners, are possible by arrangement.
- The cost of binding the lab's copies will be borne by the LPL. Payment is made via a collection list on file at Printy at the main campus. Do not forget your supervisor's business card for submission to Printy.
- You cover the cost of binding your own copy.

2 A few example codes

This chapter loosely presents some examples to help you get started with LaTeX. You will find suggestions for implementing formulas, tables, graphs, diagrams and pseudo-code. In addition, there are packages for chemical structural formulas, electrical schematics, code embedding, and more, the presentation of which would go beyond the scope here. The dummy text between the individual illustrations has as its only task to maintain a reasonable typeface despite many illustrations.

2.1 Formulas

The great strength of LaTeX are formulas of all kinds. Short formulas like $b^2 - 4ac$ can be well placed in continuous text. Unit quantities and numbers are no problem with the `SI` package. For example, $6.022 \cdot 10^{23}$ can be represented elegantly, as can velocity in $\mathrm{m\,s^{-1}}$ or the combination of all in $a = 15\,\mathrm{m\,s^{-2}}$.

Extensive formulas or whole formula packages should be set in their own environment

$$a = b + c \tag{2.1}$$
$$b = 2c + d \tag{2.2}$$

which can be easily interrupted by short text and then continued

$$\begin{aligned} a &= b + c \\ &= 3c + d \end{aligned} \tag{2.3}$$

without problems. Numbering can be suppressed either line by line by `\nonumber` or altogether by using the environment `align*`. Of course, references, such as to eq. (2.3), are also possible.

2.2 Tables, figures and plots

Table 2.1 shows a minimal example of a table. In contrast, table 2.2 is already relatively complex. The start for figures is made by fig. 2.1, which is simply included here as an external image.

Table 2.1: A minimal example of an elegant table.

Begriff	Zeichen	Einheit
Geschwindigkeit	v	$\mathrm{m\,s^{-1}}$
Anzahl	#	–

Figure 2.2, on the other hand, shows how to draw schemas with `TikZ` – the template structure in fig. 1.1 on page 3, by the way, is also created with `TikZ`. Figure 2.3 shows how you can plot functions with `pgfplots`, and fig. 2.4 finally completes this package with the ability to read, prepare, and plot your own data, and algorithm 2.1 on page 11 can elegantly display your pseudo-code.

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

Table 2.2: A somewhat more complex, but still clear table.

Parameter		Einheit	zulässige Menge	erreichtes Intervall	Optimum
Durchmesser	d_H	mm	$0.1 \ldots 2$	$0.11 \ldots 1.72$	0.811
Durchmesser	d_R	mm	$0.5 \ldots 10$	$0.56 \ldots 9.52$	0.835
Einspritzhöhe	h_H	mm	$25 \ldots 42$	$25.5 \ldots 41.5$	36.7
Einspritzhöhe	h_R	mm	$25 \ldots 42$	$26.5 \ldots 41.7$	39.3
Einspritzwinkel	γ_H	deg	$-45 \ldots 45$	$-42.3 \ldots 41.2$	14.1
Einspritzwinkel	γ_R	deg	$-45 \ldots 45$	$-44.1 \ldots 44.5$	31.9

Figure 2.1: An embedded, beautiful logo.

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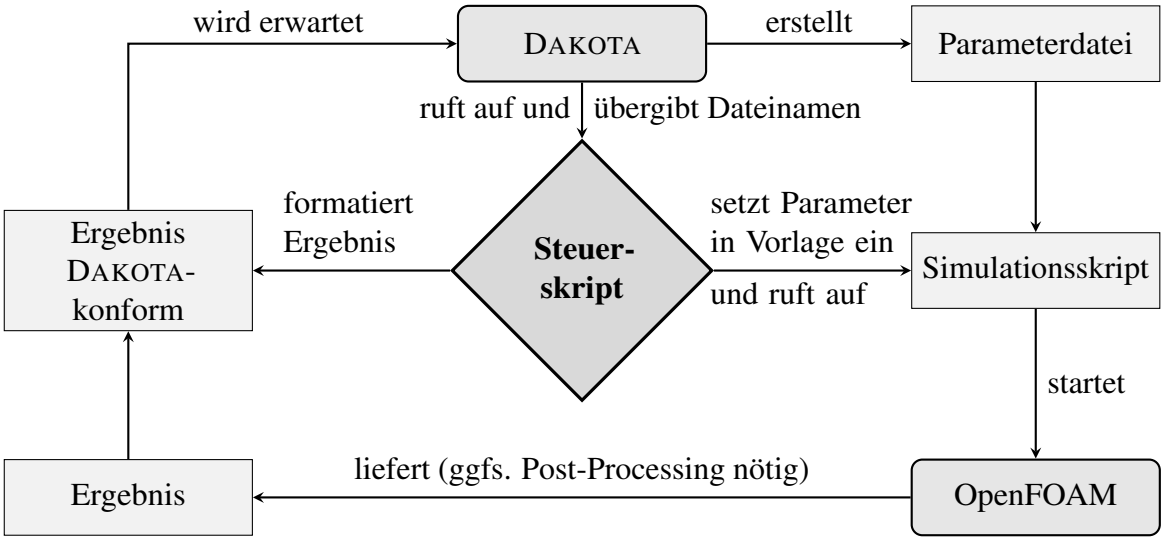

Figure 2.2: A process schema, if you predefine the different blocks once, is relatively easy to implement with `TikZ`.

this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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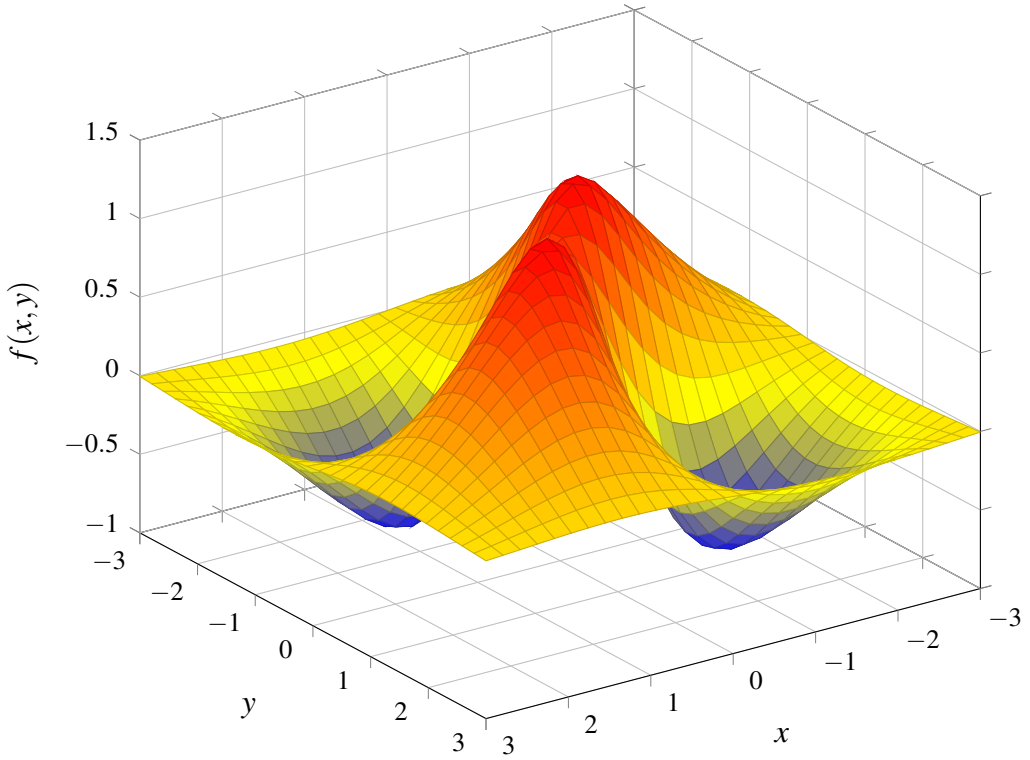

Figure 2.3: With the `pgfplots` *package, which is based on* `TikZ`*, you can draw functions, vector fields, diagrams, etc.*

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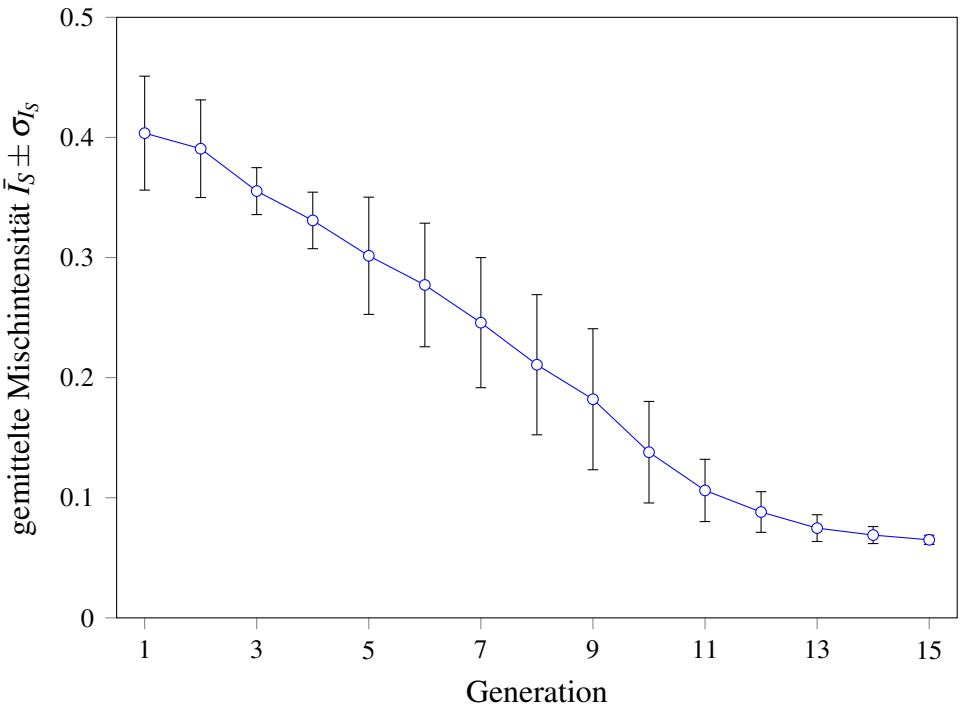

Figure 2.4: Your raw data, for example in csv format, can be read directly with `pgfplotstable` *and then edited and plotted with* `pgfplots`.

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Algorithm 2.1: You can also include pseudo code cleanly. If you want to display "real" code, on the other hand, the `lstlisting` *package is recommended.*

```
1: procedure GUILLOTINEINSERT(Bin, item, heuristic)
2:     if heuristic ← best_area then
3:         bestseg ← findTheBestBestAreaScore(item)
4:     else if heuristic ← best_shortside then
5:         bestseg ← findTheBestBestShortsideScore(item)
6:     else if heuristic ← worst_shortside then
7:         bestseg ← findTheBestWorstShortsideScore(item)
8:     else
9:         bestseg ← findTheBestWorstAreaScore(item)
10:    end if
11:    if best_rect ← TRUE then
12:        Bin.addItem(item, bestseg.outline)
13:        Bin.freesegs.remove(bestseg)
14:        spliter = Bin.freeSegsSplitter(item, bestseg)
15:        for seginspliter do
16:            Bin.freesegs.add(seg)
17:        end for
18:    end if
19: end procedure
```

the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

Appendix

A An appendix

You can structure appendices, just like your thesis, with the `\chapter`, `\section`, and `\subsection` commands. Referencing also works as usual.

If your thesis does not contain an appendix, comment out the creation of the appendix at the appropriate place in the `Thesis.tex` file.