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Project work

Bayesian Optimisation with Differentiable Simulated Priors for Particle Accelerator Tuning

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Project Work | **P — XX XX-XX —** | Study Course: L2353
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Title:
Bayesian Optimisation with Differentiable Simulated Priors for Particle Accelerator Tuning

Project Description:
Das invertierte Stabpendel, ECP Model 505, ist ein in Lehre und Forschung eingesetztes System, welches eine orthogonal zum Pendelstab verfahrbare Stange und als Messgrößen die Position der Stange als auch den Winkel des Pendelstabs besitzt [1]. Das System kann sowohl als vollaktuiertes SISO als auch als unteraktuiertes SIMO System betrachtet werden. Die Dynamik des Pendels kann durch anbringen von Gewichten sowohl an der Balancestange als auch am Pendelstab von einfach regelbar bis hin zu theoretisch nicht regelbar verändert werden. Das System besitzt kinematische und gravitationsbedingte Nichtlinearitäten. Ziel dieser Arbeit sind die Modellierung des Systems und der Entwurf eines Reglers zur Stabilisierung des Pendels in seinem linearisierten Arbeitspunkt unter Einfluss von Eingangs- und Modellstörungen. Ebenfalls untersucht werden sollen Möglichkeiten zur automatischen Anpassung von Parametern an diese Strecke, [2].

Tasks:

1. Implement BO with Cheetah prior for tuning the transverse beam parameters on a simulation of the ARES Experimental Area.
2. Evaluate the BO with Cheetah prior implementation in accordance with the evaluation in [4].
3. Evaluate timing and speed of BO with an uninformed prior vs. BO with a Cheetah informed prior.
4. Study performance under model uncertainties.
5. (Optional depending on accelerator availability) Evaluate the developed implementation on the real ARES accelerator in accordance with [4].
6. (Optional if time allows) Setup a general implementation of BO with Cheetah.

References:

[1] *Model 505 - ecp inverted pendulum*, 2000. [Online]. Available: `http://www.ecpsystems.com/docs/ECP_InvPend_Model_505.pdf`

[2] K. J. Åström and T. Hägglund, *PID controllers: theory, design, and tuning*. Instrument society of America Research Triangle Park, NC, 1995, vol. 2.

Supervisor: Jan Kaiser
Examiner: 1. Prof. Dr.-Ing Annika Eichler

Deutscher Titel:

Start Date: 17.11.2025
Due Date: 02.03.2026

January 27, 2026, Prof. Dr.-Ing Annika Eichler

Hereby I declare that I produced the present work myself only with the help of the indicated aids and sources.

Hamburg, January 27, 2026 Hiba Sikander

Abstract

This is the place for a very short abstract about your work. It should offer the reader an overview about the scope of the work and the attained results. This piece of text is also used as an announcement for your final presentation. So take care about its length and comprehensibility.

For the following text, such an abstract could look like this:

This work gives a short introduction to the typesetting tool LaTeX and points out its advantages for writing a scientific thesis. In the following, more general hints on how to write a bachelor thesis, master's thesis or project work, concerning structure, contents and representation, are given, with a special focus on how to do that in the Institute of Control Systems.

Contents

Introduction

You've just started your project work, your bachelor or master's thesis. Maybe you've already achieved some results like experiments, algorithms, methods or you've made some handwritten notes. Now you wonder how to put that on paper?

This document is both a manual, how to write a thesis, and a template that you can use for your thesis.

When you've read this document and looked through the LaTeX-files, should be able to produce your own scientific work, in a clear and visually appealing form.

LaTeXhas made steady progress over the last years. Therefore, some commands in old documents may have become obsolete. Although they might still run, there may be some better replacements available. A good summary for English documents can be found at

"*The Not So Short Introduction to LaTeX 2$_\varepsilon$*".

This work is structured in three sections. Section 1 describes how to produce a LaTeX-file using some illustrative examples. Section 2 gives a short introduction to scientific writing techniques. Finally, Section 3 is specialized on how to write a thesis at the Institute of Control Systems and presents the tools you might use here.

1 Writing with LaTeX

1.1 LaTeX's Features

This section gives some useful hints to write a thesis with LaTeX. It is important to know that LaTeX is not a WYSIWYG (what you see is what you get) program like other text editors, such as Microsoft Word. Instead it much more resembles a programming language, in which you construct your text by proper usage of syntax. The "source code" is your LaTeXfile (`.tex`).

As in other programming languages it is possible to insert comments in LaTeX that are not visible in the final text. Line wraps are not of importance while writing the text, since they are created during compilation. Therefore, formatting with LaTeXis not a big deal and should not take a lot of time, if all the logical relations are correct.

One of the big advantages of LaTeX is writing formulas. Using the logical referencing of your formulas, those references are always correct, even if you change the position of the formulas. Furthermore the print quality you achieve with LaTeX formulas is hardly matched by any other program, let alone free of charge! Citing is very easy in LaTeX, as well.

The following text is not very meaningful on its own, but if you read the source code at the same time, it is easy to understand how different elements are constructed. You should try to compile the file yourself and compare the results. If there are any differences, check if your LaTeX-configurations are correct.

1.2 Continuous Text

Writing continuous text is very easy. You can use an arbitrary text editor and just start writing, without paying any attention to formatting, line breaks, etc. If you want to start a new paragraph, just leave one or more blank lines...

So here we are now in a new paragraph. The font size is defined in the header of your main file. Emphasis is possible by different font styles. Thus when you define a new term, this is normally accentuated in *italic*, important statements in **bold** and programming code in `typewriter` or `verbatim` style.

1.2.1 Structuring Your Work

On the lowest level you can use the command `subsubsection` to structure your work.

Same Level, but Without Numbering

Have a look at the source code to see how that is achieved!

1.3 Special Objects

1.3.1 Figures

Figure 1.1 shows a block diagram.

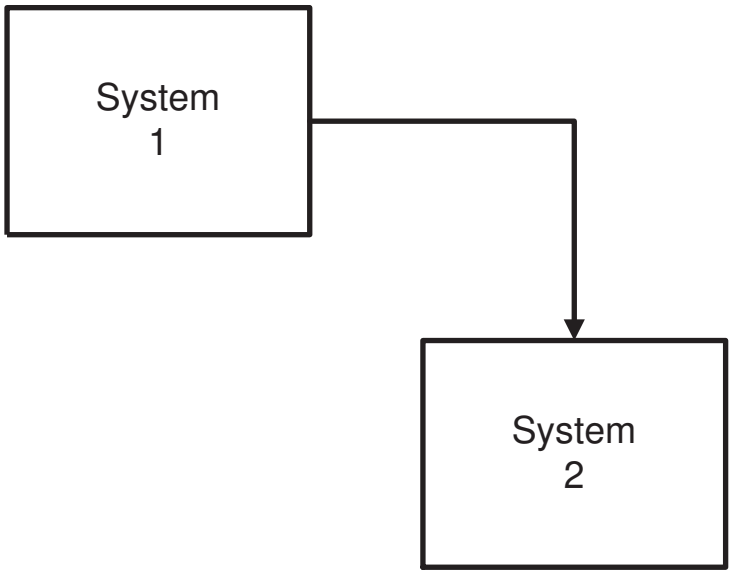

Figure 1.1: First figure

You can include figures by using the command `\afig{scale}{path/to/figure.ext}`. This works for extensions like `pdf`, `png`, `jpg`. To include tikz figures, use the command `\tikzfig{scale}{path/to/figure}`.

1.3.2 Formulas

Formulas like

$$\ddot{\phi}_1 = \frac{M_1 + l_1 \sin\phi_2(m_2 l_{s2} + m_3 l_{s3})(\dot{\phi}_2^2 + 2\dot{\phi}_1\dot{\phi}_2) - f_1\dot{\phi}_1}{\theta_1 + \theta_2 + \theta_3 + 2l_1(m_1 l_{s2} + m_3 l_{s3}\cos\phi_2) + m_3(l_1^2 + l_2^2) + m_l l_1^2}\,, \tag{1.1}$$

$$\ddot{\phi}_2 = \frac{M_2 + l_1 \sin\phi_2(m_2 l_{s2} + m_3 l_{s3})\dot{\phi}_1^2 + 2 - \phi_2\dot{\phi}_2}{\theta_1 + \theta_2 + \theta_3} \tag{1.2}$$

are typeset nicely. Keep in mind that formulas are and should be written as part of sentences and thus can and have to contain punctuation marks!

1.3.3 Symbols

Symbols like Ω can be included inline with the text. **Never** start a sentence with a symbol!

1.3.4 Citations

To cite a reference use the command `\cite{We14}` as done here: [1]. Here `We14` is the so called BiBTEX-Key. Have a look into the file "S:/Standards/BibTex/rts" to see what that means. References usually are simply attached at the end of a statement, separated by a comma, [1]. Be aware that LATEX in general provides the command `\cite`.

1.3.5 Index of Contents

The table of contents is generated automatically by LATEX. Therefore, each time you compile your main file, an `aux`-file (auxiliary) is generated that contains all information for the table of contents. This file is embedded, when you compile a second time. This holds true for all references and any change you make with respect to these requires to compile twice. An intuitive and simplified explanation is that LATEX just "reads" your files from top to bottom, taking notes in the `aux`-file while doing so. When reading your files again, the notes tell LATEX that it came across some figure, table or equation before, just like you when studying a subject.

1.3.6 References

It is possible to refer to figures, equations, etc. like this: Figure 1.1, Equation (1.2), Sections 1.3.1. See how easy that is. This is one of the main advantages of LATEX! Note that "Equation (1.2)", e.g., is capitalized. It is regarded as the figures own name. Would you write your own name in lower case?

While we are at it, have a look at the figure's caption. It uses capitalization like any other sentence in this document. Why? Because it is **not** a title, but a description.

1.3.7 Tables

Writing tables is probably the most cumbersome writing stuff in LATEX can get—and that is saying quite something! Have a close look at Table 1. It does not use vertical rules and different line weights in respective places. This is the way to design tables. If you feel the need to use vertical rules, your table is probably not very readable in the first place.

Inform yourself about some basic rules on typesetting tables:

"*Tables in LATEX 2ε: Packages and Methods*".

Table 1: A beautiful table

		Columns		
	Items	A	B	C
Rows	1	A1	B1	C1
	2	A2	B2	C2
	3	A3	B3	C3

2 Scientific Writing

The following hints are taken from the Writing-Coach, developed at the Essen University, [2]. On that German homepage

http://www.uni-essen.de/schreibwerkstatt/trainer.

much more can be found about scientific writing in German. Nevertheless lots of help in English can be found on the Internet. Also check out [3].

2.1 Correctness

Your writing should be as accurate as possible. Do not use colloquial language, neither filler or vogue words. As such, technical/scientific writing style serves a purpose: to transport information as efficiently as possible.

Respect the rules of grammar, spelling and punctuation. Text, sentences or words used in the wrong context, can lead to misunderstandings or may be hard to understand. The sentences in text documents need to be complete.

It is clear that the results of your work, e.g., experiments, are documented correctly, even though they might have had unexpected outcomes. Otherwise you do not only cause harm to you but any further research.

2.2 Comprehensibility

Correctness does not imply comprehensibility. Look at your text from the readers point of view: Consider his or her position, previous knowledge and attitude. Formulate as precisely as possible but not more than necessary. Therefore,

- choose words, that are known;
- use words that are probably unknown, such that their meaning can be deduced from the context, or explain or define them;
- do not construct deeply nested sentences.

2.3 Line of Reasoning

The line of reasoning depends on your topic and the type of text. To get a general structure, address the following six questions:

1. What is the purpose of the text?
2. What is the content? What is to be included and why?

3. What is not (anymore) part of the content? What is to be excluded?
4. Which parts of the contents belong together? What is the structure of the topic?
5. What part of the contents is suited to conclude with?
6. What part of the contents is suited to start with?

These questions show the possibilities for a line of reasoning. They show that—even for one type of text with one purpose—different lines of reasoning are possible. To choose one, it is important to analyze the topic and the content.

2.4 References

One of the most important differences between scientific writing and writing other texts is citing the references used for your work. Before starting to write your scientific text, you have probably been reading (or you still are) a lot of books, articles, conference proceedings, manuals, etc. Some may turn out to be of no interest, but some may give you the fundamental ideas.

In any case, you have to cite those references you made use of and point out all parts of your work that are based on results of others (those could even be your own results, if you have already published some work).

The citation normally follows a sentence, separated by a comma. In general you don't use direct quotes in engineering sciences, but repeat the contents in your own words for better understandability and make clear from the proper positioning of the citation—and if necessary an additional clarifying sentence—that you are referring to other work.

The bibliography follows at the end of your work, prior to the appendix. All your cited references are listed here. LaTeX offers many ways to generate such a listing automatically, which will be explained in the next chapter.

2.5 Structure

Start your scientific text with an introduction, that

- introduces the subject,
- specifies the topic,
- reflects on the problem that you are going to consider,
- defines the purpose of the work,
- explains the line of reasoning
- sketches the structure of the work.

Keep in mind that there are some readers that only read the introduction and conclusion of your work and base their decision on whether the work bears any interest for them only on these parts. To make that decision, they need to get all relevant information from those two chapters. Hint: Look at other work with a focus on that question.

The main part of your work should be structured as well, however here there are no general rules. The order of your chapters depends, if your focus was either on theoretic, methodical or experimental work. Think about a weighting for each chapter. What is reflected in volume and does not necessarily need to be proportional to the amount of time, you have spent to solve the respective problems. Sometimes it takes one week to debug a piece of code, which nevertheless should not be explained excessively.

Your work concludes with a summary of your results. Therefore have a look at your introduction: how you have specified the problem there and does it match with your results. Do not present any further results here that have been not presented in the main part. As such, always clearly separate the presentation and the discussion of results.

Finally, you end with an outlook that points out open questions. What should be further analyzed and what are possible followup projects? Do not be afraid to point out questions that came to your mind during your research, but you did not have time to properly answer. A good thesis may raise more questions than it clarifies.

3 Writing at the Institute of Control Systems

3.1 Hardware

Room N1059 is a computer pool for students to work in. You can use MATLAB/SIMULINK there to do your calculations and write your thesis.

3.2 Software

There are different editors for LaTeX. Some frequently used at the institute are TeXnicCenter and Texmaker. If you use TeXnicCenter you can import the file `Ausgabeprofile\_TeXnicCenter.tcp`, in that folder, by *Ausgabe - Ausgabeprofile definieren... - Importieren*. Choose the output-profile `\LaTeX => PS => PDF student-thesis`. Thus the settings should be correct and a PDF of your work should be generated. If that does not work, check the settings for proper paths to the post-processing and viewer programs.

Visio as graphical software is provided. If you produce figures directly with MATLAB, consider the export-setting of the "print" command.

3.3 References

The institute uses a common literature database, where a lot of books and articles that you may want to cite are already included. The respective `bib`-file can be found on `S:\ICS library\ics.bib`. Copy the most recent version to your root directory of your thesis!

Then, you can open this file with your LaTeX editor or you can use a literature manager like "jabref", for instance. Check if the reference that you want to cite is included. In this case, you can simply use the BiBTeX-key in the respective command. The literature information is properly generated only, if `bibtex` is be executed twice: first `bibtex pd` and then `bibtex main`. If you use TeXnicCenter and the provided output-setting, this is done automatically. In other cases, the easiest way would be to use the `build.cmd` file that accompanies this template. It will execute the compilation process in the proper order and open the pdf file afterwards.

Please provide with your thesis complete information on your references (title, authors, date, DOI, maybe even pdf files). We would like to include these in our database, if this has not already happened..

3.4 Binding the work

The institute offers you to print and bind the work. You need three copies in general, one for your supervisor, one for the Professor and one for yourself, and maybe more. After finalizing your work, it is also included in the literature database by your supervisor.

Your work is printed in the correct order. Put a transparent film in the front and a cardboard in the back.

Your work is stapled. Look for staples of the right length in the shelf in the computer pool and use the large stapler. Afterwards tape the back of your work. You will find illustrative material in the bibliography.

In addition to your printed work, you have to hand in a cd with the pdf file of your work and other important files. Please structure them well, such that some years later somebody else is able to find the important things. The CD is fixed inside your work at the back within a paper cover.

Last but not least, do not forget to sign the declaration.

4 Conclusion and Outlook

This work offers an introduction on how to write a successful bachelor or matser's thesis at the Institute of Control Systems.

Surely, not all your questions have been answered. Ask your supervisor and use the opportunity that he corrects a chapter before handing in your final thesis, to improve your scientific writing!

References

[1] H. Werner, *Control Systems Theory and Design: Lecture Notes*. 2014.

[2] K.-D. Bünting, A. Bitterlich, and U. Pospiech, *Schreiben im Studium: mit Erfolg: Ein Leitfaden ; mit CD-ROM* (Studium kompakt). Berlin: Cornelsen Scriptor, 2000, ISBN: 978-3589216901.

[3] N. Fenton, *Improving your Technical Writing Skills: Version 6.1*, Queen Mary University of London, 2013.