The INCOMPLETE GUIDE to Academic Writing in Robotics Research

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CHAPTER 1

Introduction

"*The word robot is drawn from an old Church Slavonic word, robota, associated with labor.*"
— by an initiate in academic writing in robotics, excitedly scribbling after a quick Google search.

So it seems that you must work on an academic text in the field of robotics. Being perhaps your first time or one of the first few times, you feel lost and confused, hoping to replicate the way you have been writing reports for your courses in undergraduate school. This time, however, your text will not be evaluated by the uninterested eyes of a TA who is simultaneously checking Instagram. Instead, your supervisor might, for the first time in your higher education, critique your writing style in detail. Bereft of hope and full of cognitive dissonance, your inner voice mumbles: "my supervisor is such a pain." Well, they might indeed be. Lashing out on Reddit can help relieve some stress, but is palliative. Instead, treating the underlying cause (poor writing) is the cure that must be sought.

If anything mentioned above hit home or if your hands itched to start your academic paper in robotics with something similar to the quote above, then you are in dire need of this guide.

1.1. What is the purpose of this guide?

The purpose of this guide is to summarize relevant points specific to academic writing in robotics research that are not already thoroughly discussed in other existing guides.

We usually introduce new contents when we, the authors, need to provide academic writing advice to our students or when examining other students (e.g., Ph.D. candidates), and those guidelines are not yet present in the INCOMPLETE GUIDE.

1.2. What this guide is not

This guide is not meant to be complete. Instead, it is focused on academic texts in the robotics field, and with a strong bias towards the authors' subfields, such as medical robotics, robot kinematics and dynamics, mobile manipulators, legged robots, and robot control. Therefore, some advice might make sense only to academic roboticists, and researchers from other fields might not find the recommendations they are looking for.

This guide will not teach you academic writing from scratch: there is good literature on relevant topics, such as mathematical writing [21], some freely available, and it is not productive to cover them all here. Instead of comprehensively covering the contents guides such as the Chicago Manual of Style (CMOS) [19] or Tubarian's book [20] present, we will point them across the INCOMPLETE GUIDE should readers need more information. Besides being incomplete by design due to our focus, the guide is still a work in progress. To emphasize parts of it that will be further written or expanded, we use the classic under construction icon:

Lastly, this guide is sometimes written in light-hearted language to be more accessible to those not yet acquainted with academic writing, so it is not bound by the strict formal prose style of academia. Therefore, you should expect somewhat humorous and mildly sarcastic statements, and a more conversational style. However, whenever we present examples, they adhere to the strict rules of formal academic writing.

1.3. To whom is this guide made for?

This guide is primarily written for students doing research or technical work in robotics, and supervisors who are somewhat weary of repeating the same things over and over. Also, non-academic professionals who did not receive formal instruction on academic writing might benefit from reading this guide. More seasoned academics might also find some useful information, especially the more opinionated ones who never opened a style guide but love to trash junior researchers when reviewing their papers. (If your blood has boiled, Reviewer 2, item 4 of Section 1.4 is for you).[1]

1.4. What should I do if I disagree with some things in this guide?

Freedom of thought is a human right: you can believe the Earth is flat but cannot be persecuted for doing so. Similarly, you have the freedom to disagree with parts (or the entirety) of this guide. All of this is regardless of your affiliation, your connection, or lack thereof with the authors of this guide.

Here are a few ideas in case you disagree with us (we do see the irony in advising on how to ignore/counter our advice):

(1) Share those thoughts with us, politely, and we might improve this guide with your point of view. Parts of it might be made clearer as well. Oftentimes, the doubts of one are shared by many others.
(2) Write your own guide. Title ideas:
    (a) A very complete guide to academic writing in robotics research.
    (b) How to hate guides: the guide.
    (c) Science is a lie: the perfect guide to pseudoscience.
(3) Silently ignore the advice given in this guide and later inform us how far you got in academia.
(4) Badmouth us on ~~Twitter~~ X.

If you are a junior researcher under our responsibility, then this guide was made for you! So please do try your best to internalize all points of this guide.

Some parts of it might be subjective, and we will try our best to make that clear when presenting something that is our personal choice. Nonetheless, most of it is objective and definitions, facts, and so on care not for your disapproval. Believing the Earth is flat does not make it, indeed, flat. Forgetting about gravity does not make you impervious to falling from great heights. And that is a good thing. Finding the truth is the role of science, regardless of one's emotions. Tampering with the truth, whether purposely or not, to fit one's biases using scientific terms is pseudoscience.

1.4.1. Appeal to (inappropriate) authority – *argumentum ad verecundiam*. This type of fallacy is related to accepting a given claim as truth *solely* owing to one's perceived authority.[2] If Zombie Einstein were to rise from his grave and proclaim: "Actually, $1 + 1 = 3$," satellites would not suddenly start falling from the sky. In the context of this guide, we, the authors, provide relevant sources and arguments for the relevant points mentioned herein. We have also defined the scope of the guide and our areas of expertise in Section 1.2.

1.4.2. "But 'X', so it is not my fault" (or, as we like to say, *argumentum ad lazy studentium*[3]). If it is one's responsibility to do something correctly, it is not acceptable for them to blame others or justify their mistakes by saying that it was due to limitations of the tools they used if the fix is feasible. Some quick examples:

Excuse: "But this was missing in the INCOMPLETE GUIDE, so it is not my fault."

Counterargument: This is a guide, not the source of all humanity's knowledge. If this guide were not available, it would still be one's responsibility to do their job correctly. Also, there are other sources that one should consult when writing academic texts, such as IEEE's style manual [10] if submitting papers to IEEE journals and conferences, and the Chicago Manual of Style (CMOS) [19], which is an

[1]The bait was thrown. Now, let's wait for Reviewer 2 to start ranting on ~~Twitter~~ X. Hopefully, they will reveal their identities.
[2]We, the authors, hope that the title of this guide is enough to clear any doubts of any claims, even if indirect, of perfection and authority.
[3]For completeness sake, note that "*lazy studentium*" is not proper Latin. Refer to Life of Brian by Monty Python.

authoritative guide and several other guides are based on it. Another good reference, which is based on CMOS but much more "user-friendly," is the Tubarian's book [20].

Excuse: "But I got this {figure, reference, example} from a past student, so it is not my fault."

Counterargument: As most parents would say, "if you see the lights inadvertently turned on, turn them off; if you see the drawer or the door inadvertendly open, close it." If something is wrong but one's is supposed to do it right, fix that something.

Excuse: "But they wrote this way in the reference, so it is not my fault."

Counterargument: If the reference states that the Earth is flat, it is one's responsibility to recognize that that statement is false and not use it.

Excuse: "But my reference manager generated the references automatically, so it is not my fault the references are wrong."

Counterargument: Those tools are not perfect and nobody told that one should use them unconditionally. If some of the references they generate are incorrect, fix them.

As an individual in higher learning, the reader is expected not to use this guide (or any other reference) as an excuse to forfeit their epistemic responsibility (e.g., the responsibility of thinking and judging by oneself). An individual that truly internalizes the concepts of this guide, instead of blindly following it, will be able to navigate the world of academic writing in robotics research beyond the topics directly covered in the INCOMPLETE GUIDE.

1.5. What is the purpose of academia?

An important aspect that should precede writing is understanding the role of academia. Academic writing is the reporting of academic work with the purpose of advancing knowledge and science. And, science, we would say, is for the good of humankind.

A lie (whether intentional or not) does not help humanity move forward. Most likely, it will put us back. Similarly to many other fields of human endeavor (like economy), academia is built upon trust. Academic texts are one of the most important deliverables of academia, which will be read and judged by others. It is expected that what is being reported was made in good faith. To keep this in check, an academic text will have to go through many gates. For instance:

(1) The writer's (many times a student) conscience. Did the student make little effort to understand concepts before running the experiments? Did the student try to cut corners in the implementation? Did the student concoct their experiments in such way to only show the good and hide the bad? Did the student knowingly hide issues in their experiments from their supervisor? Did the student tamper with data to hide that one bad trial, that awkward vibration, that one weird motion? If any of the answers so far are yes, the student is being intellectually dishonest. Many times, a student might be tempted to hide what they consider bad results because they believe that this might hurt their chances of having their thesis, paper, etc. accepted. This is wrong and counterproductive. Knowing the conditions in which a technique/implementation does not work well tend to be strong pointers towards a fix or an improvement. In addition, being honest about a "bad" result shows integrity and maturity, and explaining why it does not work in those conditions is very informative. In contrast, a "bad" result will be eventually uncovered, and one's honesty being put into question is extremely taxing on everyone involved.

(2) The student's supervisor. For the student, their commitment to academia might end within a few years. After that, they might feel safe and sound, untouchable by the consequences of whatever they might have done wrong or half-heartedly. Nonetheless, the student's supervisor and other collaborators might have much more to lose and a higher level of accountability. Proportionally to their accountability, they will know better to instruct students regarding the common pitfalls and caveats in academia and academic writing. They will know that a real system (specially a prototype) will not always work in any situation. They will question their supervisees if something looks perfect, if a graph does not

match their expectations, or if there are any other indications that a student might be cutting corners (on purpose or not). Students might be tempted to see their supervisors as the enemy (oh well, maybe you did draw the short straw!), but a well-intended supervisor will be, instead, shielding you and giving the opportunity to fix mistakes that, by external eyes, could be seen as dishonesty and treated as such.

(3) Examiners and reviewers. Theses and dissertations will be evaluated by members external to that specific research. This means that the contents being presented will be evaluated by expert, but unbiased, eyes. It is expected that examiners will be at least as strict as your supervisor. For these evaluations, the examiners will be made aware of how compliant the student has been with the supervisor's advice (or do you think all supervisors are robots? Certainly not *all* of them). In other academic settings, such as submissions for conferences and journals, supervisors and collaborators might, rightfully, not be willing to be part of an academic text that does not follow their scientific standards. Convincing one's supervisor might seem daunting, but the supervisor is often the "easiest" person in the chain. Working an extra week to fix a problem pointed out by one's supervisor is much better than having a paper rejected by the reviewers after months of waiting.

(4) Researchers that replicate the study. Surely the gates mentioned so far have held back countless improper examples of "scientific" work. In the prior gates, a student might be given a second chance to revise their work. Well, indeed, their are still learning. However, after the work is published and bad faith is found, the consequences are much more dire. A retracted work will be, for as long as the Internet exists, visible to everyone and anyone. The student's credibility, along with all their collaborators will be put into question. For example:
   - If one ever took a scientific ethics course in Japan, you might probably have heard of the anesthesiologist Yoshitaka Fujii,[4] who fabricated data in at least 183 papers. He was dismissed from his position as Associate Professor. Also, there was the STAP cell scandal, which involved Haruko Obokata.[5] After that incident, Obokata lost her job, was discredited, and a co-author, Yoshiki Sasai,[6] was criticized for poor supervision of Obokata.

(5) Society. If the student is lucky, their contribution might make its way, directly or indirectly, to be impactful in society. It might be on the spotlight or one step towards something bigger. In any case, a properly done work can influence policy and people behavior in a positive way, whereas a lie published as truth could be catastrophic. For example:
   - One of the main sources of pseudoscience for the anti-vax movement and activism, UK's former surgeon Andrew Wakefield was responsible for the "Lancet MMR autism fraud" [**6**]. Despite the evidence for scientific misconduct and conflict of interest, Andrew Wakefield's pseudoscientific texts are still taken to the letter by biased groups. The influence of his work can be connected to modern outbreaks of diseases easily preventable by vaccination [**3**].

1.6. When should I write an academic text, and what is the purpose of it?

Good writing takes time, and people often underestimate it, especially junior researchers. Academic texts such as MSc theses, Ph.D. dissertations, and articles usually have the goal of disseminating research. If you are looking into committing yourself to a career in academia, you should need no further motivation.

> "*But, Professor, I don't want a career in academia, after I graduate I'll work in The Amazing Corporation Co.!*"

Even for students who want just to get over with their theses or dissertations to graduate, their academic outputs must still serve the purpose of disseminating knowledge, and they have the moral and ethical responsibility to do it right. That is why supervisors sometimes seem to be "picky" under the eyes of students struggling to write. (Some supervisors can actually be picky, but that is another issue!) Academic texts are expected to be

[4] https://en.wikipedia.org/wiki/Yoshitaka_Fujii
[5] https://en.wikipedia.org/wiki/Haruko_Obokata
[6] https://en.wikipedia.org/wiki/Yoshiki_Sasai

authoritative, precisely because of the scientific rigor expected from them. Therefore, if they are misleading or confusing due to sloppy writing, they lose their purpose of disseminating knowledge, undermine the credibility of the scientific endeavor, and make other people waste their time. In more extreme cases, they can even lead to catastrophic results.

CHAPTER 2

Writing text

Writing can be quite daunting, even for experienced researchers. Fortunately, one can get better at it with time and through good practices. There are several key elements that enhance one's ability to write well and make the task easier and more streamlined. For example, using software that enables to write faster with fewer mistakes is crucial (quick heads-up: if you have lots of equations and want to use Microsoft Word or alike, you're doomed). Also, being familiar with style guides is very helpful because it ensures consistency and decreases the writers' cognitive load as one follows the guidelines automatically without having to think about it. As a matter of fact, for most cases, authors must adhere to specific style guides when submitting papers to conferences, journals, or writing a thesis.

For example, IEEE has its own style guide [10], and universities sometimes impose specific guidelines that students must follow. Nonetheless, university guidelines might be terse and often provide only formal rules but no best practices. Therefore, one usually relies on senior co-authors or supervisors, who also might have learned from their senior co-authors, supervisors, or through extensive practice, sometimes perpetuating writing vices and unexplained rules.

One should consult authoritative guides such as CMOS [19] when seeking specific advice and settling disputes. Scientists, academics, supervisors, and reviewers (yes, Reviewer 2, we are talking about you!) are humans with all their intrinsic biases. Some might be overly attached to a practice that can be entirely wrong or not follow the best writing practices. A writing guide such as CMOS can be handy in those cases. However, with more than one thousand pages that explain the publishing process, style and usage of the English language, and documentation (e.g., bibliography), it can be dull and more appropriate for experienced writers.

Tubarian's book [20] is an excellent alternative to CMOS. It follows CMOS's rules but is more approachable and easy to read. Being students the target audience, it includes a dedicated part composed of several chapters that cover all steps of the research and writing process. INCOMPLETE GUIDE's readers should think of Tubarian's book as a complete, generic version of the INCOMPLETE GUIDE, and it is worth reading. However, being a general guide that applies to hard sciences and humanities alike, one might find some suggestions too abstract or demanding to translate directly to robotics texts. Hopefully, this section will provide concrete and more straightforward examples that can be put into practice when writing academic texts in robotics.

2.1. Software for academic writing in robotics

> *"Oh, there is no need for using something other than Microsoft Word to write my paper. I've been using it my whole life and it's been great!" — says the neophyte, unaware of their path toward great disappointment.*

Different fields have different common practices. Maybe Microsoft Word or other WYSIWYG[1] piece of software might be perfectly fine for some disciplines that do not use many equations or advanced cross-referencing. In robotics, though, LaTeX[2] is much more widespread, and most conferences and journals make LaTeX templates available. The reason for that is because LaTeX is an advanced open-source typesetting system that generates professional-quality formatted documents, including beautiful equations and a powerful cross-referencing and citation system.

The main drawback of LaTeX, though, is the steep learning curve. Working in LaTeX seems much more like programming than writing regular text because what you write is not what you see in the final document.

[1] https://en.wikipedia.org/wiki/WYSIWYG
[2] https://www.latex-project.org/

Instead, the user is more concerned with content and structure whereas LaTeX is responsible for formatting the document according to a well-crafted template.

There are many LaTeX editors that are user-friendly and have a much less steep learning curve. Our favorite, LyX,[3] is an open-source software that we use to write the INCOMPLETE GUIDE and all of our papers. Differently from most LaTeX editors, LyX instantly shows equations and tables, which makes the process of writing much more streamlined.

2.2. Version control

> *"Yes, I have the latest version of the paper here somewhere... wait a second..." — the person who does 'version control' as shown in Figure 2.2.1, with sweaty hands, on the verge of complete despair over an impending deadline.*

In Figure 2.2.1, we show one example of what does **not** constitute proper version control. Does it look familiar?

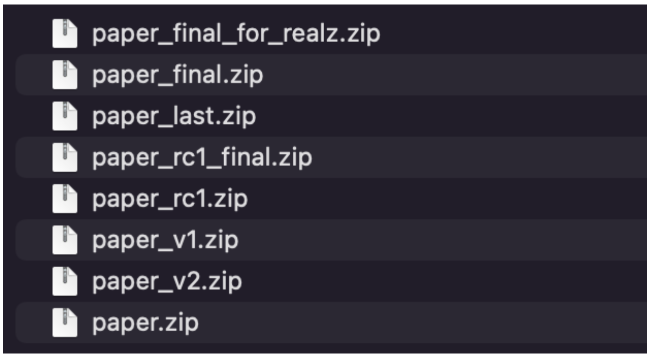


FIGURE 2.2.1. How **not** to do version control of your text.

Source files for academic texts (much like software source-files and other assets) quickly become an intricate composition of intertwined files. Many times an academic text needs to be worked on collaboratively by several people. With this in mind, use Git[4] to version control all files related to a given paper in a proper repository. Some desktop applications are also available, but in any case you can do enterprise-level source control of your texts by learning only some commands: `clone`, `pull`, `add`, `commit`, and `push`.

Websites such as Github[5] and Gitlab[6] offer generous amounts of storage for *private* repositories. Use the best one as directed by the person in charge in your group.

Note that a repository related to your academic work should **never** be made public unless you have the permission of your supervisor and other possible collaborators.

2.2.1. Common pitfalls and general advice.

One should always maintain a tidy repository and ensure that everything is neatly organized. To that aim, a requirement is for one to sufficiently understand what they are doing. Therefore, students should be familiar with the basic commands. One common mistake, especially for those looking for shortcuts, is to use the command

```
git add *
```

Please, don't do that! Because `git add` will add files that are meant to be versioned, the `git add *` means that all files in the current folder will be added to the repository, **including temporary ones**. Given that the temporary files in one computer will not match those in another computer, this could cause pesky merge conflicts that will take longer to fix than to learn the proper usage of `git add`.

[3] www.lyx.org
[4] https://git-scm.com
[5] https://github.com
[6] https://about.gitlab.com

2.3. Purpose, target audience, how much details should be included

Because academic texts are meant to disseminate knowledge, academic writers should write in a way that is as easy as possible for their audience to understand it. This does not mean that the contents will necessarily be easy or simple to understand, especially when the target audience is very advanced. However, it should not be more complicated than necessary. Different writers have different abilities, and this will be reflected in the quality of their writing. Nonetheless, writers must not be sloppy or cut corners to make their lives easier because it invariably implies in making the readers' learning process much more difficult than necessary. (Nobody denies that the learning process can sometimes be tough and frustrating, but being miserable due to someone else's poor writing is far from ideal.)

A common question is how much detail one should include in a report, paper, etc. Just because one has struggled to understand a given topic, it does not mean that elementary information should be included, unless the target audience is not expected to be familiar with it. For example, when writing a paper at the Ph.D. level for an international robotics conference, it is unnecessary to include references or comprehensive explanations of basic facts about physics, such as Newton's second law ($F = m \cdot a$). However, if one is writing about discrete event systems modeled by Petri nets or automata [5], it is advisable to introduce the topic briefly with corresponding references. On the other hand, if the same paper is submitted to a conference on discrete event systems, the amount of introductory detail about Petri nets should be substantially shortened as the audience is expected to be familiar with them.

It is shockingly common for students to naively write about the definition of a robot or Asimov's laws in their introductions. That is one of the best ways of tempting experts in the field to skip that section altogether! So, unless the subject of the academic text in question is to present an in-depth discussion of Asimov's laws [16] or challenge the definition of a robot, it is better to defer the topic to outreach texts or the nearest pub, as the tongue in cheek statistics in Fig. 2.3.1 shows.[7]

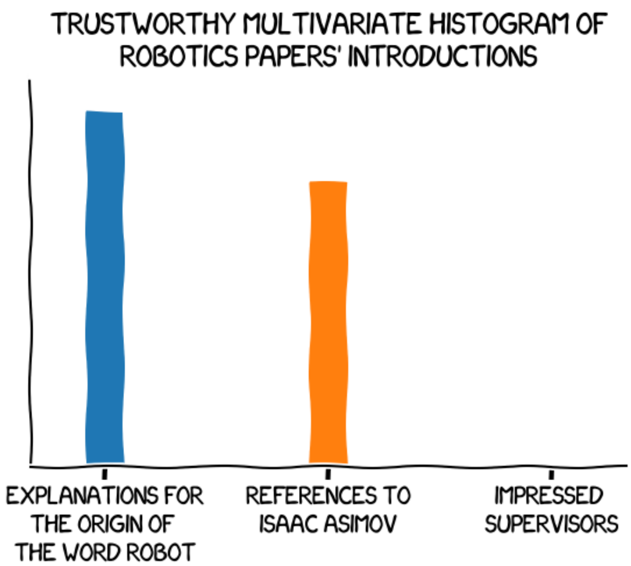


FIGURE 2.3.1. A (supposedly true?) multivariate histogram of robotics papers' introductions.

In any case, the text should have a logical flow, a thread that ensures that information is effectively conveyed, constrained by the length limit of the text. Communicating the same idea in shorter texts is much more demanding than when there is no page limit because it requires understanding how the target audience usually understands the subject. Also, it requires having a broad understanding of the knowledge field because high-quality references are needed not only to support one's claims but also to signpost readers to relevant

[7] There is always a fine balance between academic accuracy and readership engagement. The conclusion of whether this histogram was generated from real data or not is left as homework.

background information. Without knowing the field, writers might end up "rewriting calculus" (analogous to "reinventing the wheel") when good references would suffice.

A common mistake is to overexplain elements that are not part of the contributions in one's particular work and will not help the reader understand what has been proposed or done in the author's work. Indeed, anything not proposed or implemented in the author's work must be preferably left out of the text for the authors to focus on the crucial: contributions of *their* work. If concepts proposed in another work are necessary for the target audience to understand the author's work, one might present them very briefly. In that case, one must always clarify, through citations and proper text segmentation, that those concepts have been proposed in another work. Note that *another* work also includes other works from the same authors.

2.4. Structure of an academic text

Different academic texts, such as theses, articles, and reports require a slightly different structure. Nonetheless, there are several common sections that readers expect to see, the most common ones being the following (titles might vary according to the specific research subfield).

2.4.1. Title. The title should be concise but descriptive. It should reflect what the work is about and not create false expectations. For example, if one is writing an undergraduate thesis that describes the implementation of a motion controller from the literature on a differential-drive mobile robot, a title such as *"A new controller for robots"* is not adequate. First, it is misleading because the work consists of implementing an existing motion controller, not on proposing a new one. Second, it is too generic. To remedy the aforementioned problems, we can use increasingly enhanced titles.

For instance, *"Implementation of a motion controller on a mobile robot"* eliminates the false expectation because it emphasizes that the work deals with the implementation, not the proposal, of a controller. Moreover, it specifies the type of controller being implemented, as well as the robot.

Nonetheless, the title can be improved even further: *"Implementation of a nonlinear motion controller on a differential-drive robot."* Now readers can expect a differential-drive robot, not a car-like one or any other type of mobile robot, and a nonlinear controller, not a linear one.

Still, from the improved title, one does not know if the motion controller is used for path following, trajectory tracking or set-point control. Therefore, a straightforward enhancement would be to specify the type of motion controller: *"Implementation of a nonlinear trajectory tracking controller on a differential-drive robot."*

One could go one step further to describe even more the type of nonlinear controller, but this is a gray area because the title starts to become long. For instance, *"Implementation of a feedback-linearization-based trajectory tracking controller on a differential-drive robot."* Alternatively, *"Implementation of a trajectory tracking controller based on feedback linearization on a differential-drive robot."* Titles that are more detailed than those latter two might be overly long and should be avoided.

2.4.2. List of authors. The list of authors is perhaps one of the main minefields in a paper containing multiple authors, especially if they belong to different research groups. It should be defined *before* the paper is written in common agreement with everyone involved. Different fields adopt distinct ordering and criteria for authorship, which can also be affected by different countries and institutions. To complicate the matter even further, most people seem to have strong opinions about it, sometimes without being aware of this diversity of options and possibilities.[8] For instance, researchers in some fields might prefer to list the authors alphabetically, regardless of their contributions. Others might prefer to list the authors decreasingly according to their contributions; the one who contributes the most is the first whereas the one who contributes the least is the last author. Another common approach is to list the lead author first, oftentimes a Ph.D. student or postdoctoral researcher, the principal investigator or supervisor last, and everybody else in between in a decreasing order of contributions. So, no wonder it can be quite confusing when junior researchers are writing or contributing to their first papers.

[8] In our experience, many researchers, including the more experienced, never bothered thinking deeply about this. They "learned" it from their supervisors or research groups without reflecting on their practices' ethical implications or long-term consequences.

The main rule of thumb for authorship is that if one *clearly* has not contributed to the paper, they should not be included as an author. Conversely, if one *clearly* contributed to the paper, they must be included. As usual, the devil is in the detail, which is the definition of what constitutes a "clear contribution." The Contributor Role Taxonomy (CRediT) [2],[9] a framework adopted by several big publishers, such as Elsevier,[10] helps define the contributions. It lists the following contributions:

Conceptualization: Ideas; formulation or evolution of overarching research goals and aims.

Methodology: Development or design of methodology; creation of models.

Software: Programming, software development; designing computer programs; implementation of the computer code and supporting algorithms; testing of existing code components.

Validation: Verification, whether as a part of the activity or separate, of the overall replication/ reproducibility of results/experiments and other research outputs.

Formal analysis: Application of statistical, mathematical, computational, or other formal techniques to analyze or synthesize study data.

Investigation: Conducting a research and investigation process, specifically performing the experiments, or data/evidence collection.

Resources: Provision of study materials, reagents, materials, patients, laboratory samples, animals, instrumentation, computing resources, or other analysis tools.

Data Curation: Management activities to annotate (produce metadata), scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later reuse.

Writing (original draft): Preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation).

Writing (review & editing): Preparation, creation and/or presentation of the published work by those from the original research group, specifically critical review, commentary or revision – including pre-or post-publication stages.

Visualization: Preparation, creation and/or presentation of the published work, specifically visualization/ data presentation.

Supervision: Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team.

Project administration: Management and coordination responsibility for the research activity planning and execution.

Funding acquisition: Acquisition of the financial support for the project leading to this publication.

Still, CRediT does not prescribe criteria for authorship or the ordering of the authors list, which should still be agreed upon, ideally *before* starting writing the paper. (Has the reader noticed that we have emphasized it a second time?) One thing that should be always clear, though, is that time invested does not equal contribution. For example, suppose two authors agree on listing them decreasingly according to their contribution. If one spends 90% of their time contributing to 10% of the paper and the other author spends 10% of their time contributing to 90%, the one contributing 90% should be listed first. Young researchers struggle to understand this, especially students contributing to their first papers. However, we should all acknowledge that people should not be penalized for efficiency. Nonetheless, when supervisors write academic articles with their students about their students' research, it is common for the students to come first and the supervisors last, even if the supervisors contribute more. This is usually accepted as part of the mentoring process, and some supervisors might be very engaged with their students' research. Hence, they might eventually contribute more. Nonetheless, even if it is common practice to list students first, they should discuss it with their supervisors, especially if they feel that the supervisors contributed substantially more than them.[11]

[9] https://credit.niso.org/

[10] https://www.elsevier.com/en-gb/researcher/author/policies-and-guidelines/credit-author-statement

[11] This is a note for eventual hands-off researchers reading this part, who might be frowning in discomfort. There exist senior academics who actually engage with research at a non-managerial level!

2.4.3. Abstract. A good abstract usually briefly presents, in this order, the overall context and the problem to be tackled, the main limitations of current techniques, the technique used to overcome those limitations, and the main results with corresponding insights. Of course, sometimes more or fewer details can be included, but this outline tends to be sufficient. Let us consider the abstract from [**15**]:

> "*Robotic assistance allows surgeons to perform dexterous and tremor-free procedures, but robotic aid is still under-represented in procedures with constrained workspaces, such as deep brain neurosurgery and endonasal surgery. In these procedures, surgeons have restricted vision to areas near the surgical tooltips, which increases the risk of unexpected collisions between the shafts of the instruments and their surroundings. In this paper, our vector-field-inequalities method is extended to provide dynamic active-constraints to any number of robots and moving objects sharing the same workspace. The method is evaluated with experiments and simulations in which robot tools have to avoid collisions autonomously and in real-time, in a constrained endonasal surgical environment. Simulations show that with our method the combined trajectory error of two robotic systems is optimal. Experiments using a real robotic system show that the method can autonomously prevent collisions between the moving robots themselves and between the robots and the environment. Moreover, the framework is also successfully verified under teleoperation with tool-tissue interactions.*"

It contains all the aforementioned elements that make up a good abstract, as we can see in Table 1.

Notice that the length of abstracts can vary greatly. Paper abstracts usually have a much shorter length when compared to abstracts of theses and dissertations. Also, the word count is usually determined by the style guides and institutional policies.

2.4.4. Introduction. The introduction section is crucial to capture the readers' attention and gently introduce the subject to an audience that not necessarily is an expert on the subject being presented. It usually provides context for the work, as well as the motivations, objectives, and statement of contributions. In shorter academic texts, such as papers, it is common to place the literature review and the state of the art in the Introduction section. In theses and dissertations, the literature review and state of the art are placed in a different chapter.

2.4.5. Literature review and state of the art. The literature review and the state of the art, although closely related, are different things. The literature review contextualizes one's work with respect to prior work that has been (usually) published in scholarly literature. Sometimes, it makes sense to cite seminal, old papers for the sake of historical accounts, or because techniques presented in those papers are highly relevant to the current work. The state of the art, on the other hand, is part of the literature review but accounts for the best, most current techniques published so far.

For example, when talking about hierarchical control of redundant robots, one might cite the pioneer work by Liégeois [**13**]. That work was the first to propose projecting the control signal related to a low-priority task onto the null-space of the Jacobian of the high-priority task. This way, the low-priority task is executed as best as possible, but with no convergence guarantees, without disturbing the high-priority task, whose convergence is not affected by the low-priority task. Albeit being a pioneering work and fascinating, it is not the state of the art. More recent hierarchical controllers include features and properties not found in Liégeois's work, such as equality and inequality constraints [**7**], which are very important when including obstacle avoidance and other geometrical constraints in the controllers. Although other works have built upon Escande et al.'s work [**7**], such as Lee et al.'s [**12**], they tackle slightly different problems, and the latter does not supersede the former. Therefore, we can consider that both [**7**] and [**12**] are the state of the art.[12]

2.4.6. Mathematical background or preliminaries. This chapter or section usually presents the technical contents that are important to understand the academic work at hand, but are not the main part of the

[12]Of course, they are the state of the art at the time of writing this paragraph; namely, at 21:18 on 11 August 2022. If the INCOMPLETE GUIDE survives the relentless passage of time, this example will invariably become obsolete.

Table 1. Examples of main points to discuss in an abstract and what they mean in plain English.

Main points	Excerpt from the abstract	What it means in plain English
Context	*"Robotic assistance allows surgeons to perform dexterous and tremor-free procedures, but robotic aid is still under-represented in procedures with constrained workspaces, such as deep brain neurosurgery and endonasal surgery."*	Robots are cool and useful in surgical procedures, but they are not widely applied when the surgery is done in a very small cavity. I'm intrigued!
Problem and challenges	*"In these procedures, surgeons have restricted vision to areas near the surgical tooltips, which increases the risk of unexpected collisions between the shafts of the instruments and their surroundings."*	Robots are not widely used when the surgery is done in a very small cavity because surgeons cannot see well what's happening. So, the tools surgeons use might collide with one another and even with the patient. That's dangerous!
Technique used to overcome those limitations	*"In this paper, our vector-field-inequalities method is extended to provide dynamic active-constraints to any number of robots and moving objects sharing the same workspace."*	The technique is based on an extension of the vector-field-inequalities method. Now it can be used to any number of robots and even when objects move!
How the method was evaluated	*"The method is evaluated with experiments and simulations in which robot tools have to avoid collisions autonomously and in real-time, in a constrained endonasal surgical environment."*	The proposed technique was evaluated in computer simulations and with the actual robot in the nose's cavity.
Main results with corresponding insights	*"Simulations show that with our method the combined trajectory error of two robotic systems is optimal. Experiments using a real robotic system show that the method can autonomously prevent collisions between the moving robots themselves and between the robots and the environment. Moreover, the framework is also successfully verified under teleoperation with tool-tissue interactions."*	The method results in an optimal trajectory error, it prevents collisions between the robots and with the environment, and was used in teleoperation in which the robot tool interacts with a tissue.

work itself. It usually lays down the main notation and concepts used across the text, but advanced readers should be able to skip it without any loss of continuity. This section (or chapter) might also include a subsection to describe the problem being investigated.

For example, a paper that proposes a new probabilistic path planner in the configuration space might use a "Preliminaries" section to introduce concepts such as configuration, configuration space, local path planner, etc. It might also describe the path planning problem because this problem usually has different meanings and definitions depending on the particular field. Indeed, academics working on operations research will likely have a different understanding of path planning than roboticists. Sometimes, even roboticists might see problems from different angles. Having an accurate problem definition eliminates any ambiguity.

Another example would be a Ph.D. thesis that introduces a new methodology for modeling and control of reconfigurable robots using different mathematical representations. If those mathematical representations are novel, they are part of the thesis contributions and would deserve a dedicated chapter. However, if the methodology for modeling and control of reconfigurable robots employs an uncommon mathematical representation that was proposed elsewhere, then a brief explanation of that mathematical representation should be placed in the Mathematical Background section.

2.4.7. A chapter or section (or more than one) to describe the technique being proposed (i.e., methodology). This section is usually generically referred to as "Methodology." However, a more descriptive name is almost always used in most robotics subfields. Therefore, depending on the research or technical subject being developed, this section might have different titles, such as "Controller Design," "Robot modeling," and "Mechanical design." Still, it is more appropriate to be slightly more specific to better convey the technique being employed. For example, "Constrained Kinematic Controller Design" is more informative than just "Controller Design."

2.4.8. Results. In more applied papers, this section usually presents the results from realistic simulations or actual experiments. If the work concerns more theoretical results, this section might present numerical evaluations. In all cases, it is usually required or highly desirable to compare the proposed techniques with the state of the art.

For example, if a paper is proposing a new path planner for highly redundant robots, one should expect not only simulations and experiments highlighting the properties of the proposed technique, but also a thorough comparison with relevant state-of-the-art techniques to highlight the advantages and disadvantages of the proposed method.

In academic texts that do not require novelty—that is, pushing the boundary of knowledge is not necessary—such as undergraduate theses, comparisons with the state of the art are not required. Nonetheless, simulations or experiments are usually still required to evaluate the studied technique, either qualitatively, quantitatively, or both. If possible, comparisons with other techniques are also desirable, even if they are not state-of-the-art.

In any case, good experimental planning is complex and takes time. When talking to young researchers about how they intend to evaluate the method they have used or proposed, a standard answer is, "I will compare my method with X," where X can be any technique they think is "popular" (see fallacy *ad populum* in Section Y). The natural follow-up questions would be "Compare what?", "What metrics will you use?", "Why are comparisons done in the first place?" Again, a typical answer is to compare the efficiency, precision, robustness, or optimality to show that one's method is better than the one they used for comparison. Often, students will struggle to define those terms more generally or even in the more specific context of their projects. One of the many reasons is that they might not have a clear problem statement in the first place. Therefore, trying to compare something undefined is an ill-defined task.

Notwithstanding, even when the problem statement is well-defined, terms such as efficiency, precision, etc., are commonly mentioned only vaguely, despite being precise concepts. Indeed, they have become buzzwords that people usually use in day-to-day activities to denote good properties. Therefore, they sound like a good guess to answer the questions of nosy supervisors! However, trained researchers, such as supervisors, reviewers, and examiners can spot the vagueness from miles away.

So, what is the purpose of comparisons in the first place? Comparisons are usually required because almost new technique builds upon the state of the art. Remember the quote widely attributed to Newton, "If I have seen further [than others], it is by standing on the shoulders of giants." In other words, strictly speaking, almost any scientific paper is incremental in the sense that it improves something that already exists and very rarely a new paradigm is created or proposed.[13] Therefore, comparisons are meant to *evaluate* how the proposed method performs with respect to existing techniques. Nonetheless, even when a new paradigm is proposed, comparisons might still be relevant to highlight its benefits. In that case, however, one should be careful not to "compare apples with oranges." For example, metrics to compare the ability of a ground robot ("the apple") to overcome obstacles on the floor will likely not make sense to use with an aerial robot ("the orange").

[13] The reader should bear in mind that the term "incremental" is commonly used in a derogatory manner, implying that the work offers little to nothing to the state of the art. This usage is likely to be a byproduct of the frown-upon practice of publishing fragmented papers, the so-called LPU, or least publishable unit [4].

Rigorously speaking, any well-thought method evaluated through a well-designed experiment in a paper that offers new insights should merit being published, even if the proposed technique ends up performing worse than the state of the art. Alas, most fields tend to be reluctant in accepting negative results, even when they improve our understanding about a particular field [17]. This aversion tends to be exarcerbated in more technical fields, such as robotics, due to their intrinsic utilitarian nature.[14] Therefore, there is a bias towards techniques that bring clear advantages over existing methods, and those advantages are usually highlighted through qualitative and quantitative results.

Nonetheless, regardless of biases in our field, comparisons should be insightful and non-trivial for the intended audience.

Disclosing *small* implementation details. The implementation should accurately match the description in the paper. Any minor "implementation details" should be clearly disclosed and, if major, they should be included in a section entitled "Implementation Details." In the latter case, one should consider including the Implementation Details section within the "Methodology" section. One classic example is to design controllers in the continuous domain but have a discrete implementation. This practice is so common that many people omit it, or make it implicit by explaining the discretization effects when describing the results. However, a better practice is to mention it explicitly, even if briefly.

Supose we design a continuous robot motion control law for a fixed-base manipulator robot as

$$\boldsymbol{u} = -\boldsymbol{J}^{+}\lambda\tilde{\boldsymbol{x}}, \tag{2.4.1}$$

where $\boldsymbol{u} \in \mathbb{R}^n$ are the joints' velocity inputs, $\boldsymbol{J}^{+}$ is the pseudoinverse of the task Jacobian $\boldsymbol{J} \triangleq \boldsymbol{J}(\boldsymbol{q}) \in \mathbb{R}^{m\times n}$, with $\boldsymbol{q} \in \mathbb{R}^n$ being the configuration vector, and $\tilde{\boldsymbol{x}} \in \mathbb{R}^m$ is the task error vector. Even if the robot is velocity-actuated (i.e., the robot joints accept velocity commands), it receives control inputs according to a sampling period instead of continuously. Therefore, one could state, "As the robot joint controllers operate at a frequency of 1 kHz, the control law (2.4.1) is calculated at each 1 ms and passed to the robot using high-speed serial communication." This way, readers will understand that the controller operates at a frequency of 1 kHz and that computation and data transfer must be done under 1 ms. Suppose now that the robot is position-actuated. In this case, (2.4.1) must be integrated before sending the signal to the robot. Thus, this numerical integration must be disclosed as it will introduce new dynamic behavior that is not accounted for in the controller's mathematical formulation. Not doing it will potentially mislead readers, which is lousy science communication at best, but potentially academic malpractice if done maliciously to cover unexplained behavior in one's results. The description of this implementation "detail" might be as simple as, "The control inputs are discretized using the forward Euler method with a sampling period of 10 ms and fed into the robot's joint position controller, which runs at a frequency of 100 Hz."

2.4.8.1. *The role of theoretical results in guiding experimental evaluation.* Formal theoretical analysis can be a valuable guide when assessing results experimentally. Suppose the goal is to assess the closed-loop behavior of a system under a given control law. This could be, for instance, the convergence properties for the positioning of a manipulator end-effector. If the theory predicts that the error will converge exponentially to zero with convergence rate determined by a positive scalar gain λ, the experimental evaluation can be as simple as verifying that this is indeed the case for typical setpoints and different gain values when all the assumptions are fulfilled.

However, it is common to design techniques for an ideal case and implement them on real systems that mildly violate some assumptions. A typical case is designing robot controllers in the continuous time domain and implementing them on a digital computer. In that case, it might be worth showing the system behavior under different sampling periods and contrasting with the ideal behavior.

Now, suppose that one proposes a singularity-robust motion control technique for a serial manipulator with strong theoretical properties. For instance, let us say that the theory predicts that the end-effector positioning error exponentially converges to zero when the robot is far from singular configurations, but the robot speed goes

[14] Although most researchers will agree that robotics intrinsically is a practical or applied field, others acknowledge theoretical robotics as a legitimate subfield [18].

asymptotically to zero as it approaches singular configurations with decrease rate determined by a positive scalar β. The greater the parameter β is, the greater is the decrease rate at the expense of distorting the behavior far from singularities. In this case, one would expect at least a qualitative comparison between the regular controller and singularity-robust controller both far and close to singularities under different combinations of λ and β. This comparison should provide useful intuitions on how to tune those parameters and insights regarding the closed-loop behavior.

2.4.8.2. *Common organization of the results section.* It is common practice to include a subsection or introductory paragraph describing the hardware and software used to obtain the results. It usually lists the computer specifications (e.g., processor, memory), robots and sensors with their main characteristics (e.g., 7-DoF Kuka LWR, a VICON motion capture system with 8 cameras mounted around a 2.4 m × 3.6 m metallic pool), software (e.g., Ubuntu 22.04.4 LTS with OpenCV 4.9.0 for computer vision and DQ Robotics for dual quaternion algebra manipulations).

2.4.9. Conclusions. The Conclusions section briefly restates what the paper is about, summarizes the main findings and insights, and provides insights, including proposals for future works. It should be complementary to the Introduction section, not a mere repetition of information already written in the text.

2.4.10. Appendix (or Appendices, when there are more than one). The appendices are used for information that are of secondary importance. Their contents can be removed from the main text without loss of continuity, but usually are valuable to readers who need more details. For example, in a more theoretical paper, dissertation, or thesis, intermediate, less important but intricate proofs can be placed in an appendix to make the reading flow of main results smoother and more direct. On the other hand, sometimes additional graphs can be put in an appendix, for the sake of completeness, without compromising the presentation of main results.

2.4.11. References. If one is using LaTeX/LyX, this section is generated automatically with the references cited in the text. Other word-processing software, such as Microsoft Word, have plug-ins that ease the task of managing references, but they are usually less robust than LaTeX and definitely less streamlined than LyX.

The number of references depends solely on one's claims and what they want to convey. Therefore, there is no exact number or threshold that determines if a report, paper, dissertation, or thesis are good or not. Authors are expected to contextualize their work with respect to the existing literature, so the number of references should reflect their understanding of the topic. This means that those references should be directly associated with their work, and they should discuss them critically. References should help the reader to understand the technical field, and how one's work is inserted into the big picture. On the other hand, if the authors put references that are not so relevant or they do not discuss them appropriately, the reader will have the feeling that the authors don't understand their technical field and probably will be confused. Also, appropriate references should be used to support any claim that one makes that is not common knowledge (there is no need to put any reference to state that the sun is bright and hot),[15] and for any technique that the authors haven't developed themselves. Since any technique that one might propose likely derives from previous ones, the predecessor techniques should be appropriately cited.

2.5. Verb tenses

The use of verb tenses in the scientific literature change according to different style guides. Nonetheless, some usage is common across all different styles. For instance, future tenses are good to describe future works (e.g., "future works will focus on solving the problem of navigating under extreme disturbances"). In an academic text that is used to describe a developed work, the present tense should be used to describe current features of the developed system (e.g., "the robot has 30 actuated DOF and a non-actuated floating base") and universal truths (e.g., "light has a maximum speed"). Finished experiments that were done must be referred to

[15] Nonetheless, if one needs to indicate *quantitatively* how bright and hot the sun is (e.g., in astrophysics papers), then an appropriate source must be cited.

using past tense (e.g., "we performed a series of experiments to evaluate the robot's behavior when interacting with humans").

A less uniform usage of verb tenses across different style guides arises when describing previous works, most notably when writing a literature review. For instance, CMOS accepts both present and past tenses when referring to works in the past.[16] However, one should be consistent in the use of verb tenses. For example, according to CMOS, it is equally fine to say

> *"Adorno and Marinho* [1] *introduces a guide that is incomplete but fun to read"*
>
> or
>
> *"Adorno and Marinho* [1] *introduced a guide that is incomplete but fun to read."*

Other guides, such as APA, recommend using past or present perfect when discussing other researcher's work.[17]

The previous discussion indicates that some guides reject using the present tense when referring to published works. Others, however, accept present, past, and past perfect tenses as long there is consistency. That seems confusing! There are several ways of settling this matter. For instance, when submitting a paper to a journal that adopts the APA style guide, only the past tense or present perfect should be used when discussing prior works. Also, sometimes coauthors (especially senior ones) are very opinionated and adamant about a given usage. It might be a good idea to stick with their recommendation/tyrannical request/order/decree. After all, they might want to maintain consistency across their publications, which is also fair, at least from their point of view. But what if nothing is dictating the verb tense one needs to use when discussing previous works?

A good rule of thumb is to use present tense for a technique that is currently widely used, present perfect for techniques currently used but on the verge of being superseded (often by the technique one is proposing), and simple past for things that are widely accepted as being outdated or with a defined date in the past. For example,

> "Clifford $\underbrace{\textbf{introduced}\text{ dual quaternions in the 18th century}}_{\text{[past tense] clearly defined date in the past}}$, which $\underbrace{\textbf{are}\text{ becoming widely used in robotics research}}_{\text{[present tense] fact}}$. Indeed, several researchers $\underbrace{\textbf{have proposed}\text{ advanced kinematic models}}_{\text{[present perfect] in the past but not entirely outdated}}$ based on dual quaternion algebra, although very few $\underbrace{\textbf{have proposed}\text{ dynamic models using dual quaternions}}_{\text{[present perfect] those techniques are about to be superseeded}}$. For instance, McCarthy $\underbrace{\textbf{has proposed}\text{ a model for cooperative manipulators}}_{\text{[present perfect] McCarthy's technique is still in use}}$ based on generalized forces in dual quaternion form. However, that model $\underbrace{\textbf{relies}\text{ on the matrix representation of dual quaternions}}_{\text{[present tense] fact}}$, which $\underbrace{\textbf{is}\text{ more inefficient than the hypercomplex representation}}_{\text{[present tense] fact}}$ and $\underbrace{\textbf{lacks}\text{ an intuitive geometrical meaning}}_{\text{[present] fact}}$. In this paper, we $\underbrace{\textbf{propose}\text{ a new dynamic model for humanoids formulated using dual quaternions in hypercomplex form}}_{\text{[present] the authors are doing it in the current paper}}$. This new formulation $\underbrace{\textbf{is}\text{ computationally efficient}}_{\text{[present tense] claim}}$ and $\underbrace{\textbf{has}\text{ a straightforward geometrical interpretation}}_{\text{[present tense] claim}}$."

2.6. Terminology

The terminology must be precise within the context of the target audience. Some terms that usually used colloquially in daily life might have a precise (despite of the informal use as a synonym) meaning in robotics, control, and associated fields. The precise use of those words might contrast with their use in literature or the news, where they might have a looser meaning. CMOS [19] presents a comprehensive glossary of problematic

[16] See https://www.chicagomanualofstyle.org/qanda/data/faq/topics/Usage/faq0187.html
[17] https://apastyle.apa.org/style-grammar-guidelines/grammar/verb-tense

words and phrases in English. Here we focus on words and expressions that are usually misused in the robotics literature.

Classical/classic: A common mistake that even native speakers make is to use classical instead of classic. According to the Cambridge dictionary,[18] the adjective "classic" refers to the most typical example of something. For example, the RRT algorithm [11] is a classic algorithm for motion planning in the configuration space. Classical, on the other hand, is an adjective that refers to the culture of the past and art forms. Therefore, we say that Monalisa is a classical painting.

Impossible: Unless something is physically or mathematically impossible (e.g., traveling faster than light or dividing a number by zero), one should not use it as a synonym for impractical or unfeasible. If something is very hard, but no one has proved its impossibility, it does not mean it is impossible.

Master/slave: Those expressions are charged with a negative connotation and should be avoided, especially because there are good alternatives that convey the same meaning. The IEEE Technical Committee on Telerobotics[19] recommend using one of the following alternatives: haptic device/remote robot, leader/follower, driver/driven, or teleoperating/teleoperated.

Optimal: Optimality is related to an objective function that is either minimized or maximized. Therefore, there is no sense saying that something is more optimal than another thing. Also, optimal cannot be used subjectively.

Perfect: Something perfect cannot, by definition, be improved. Therefore, it is impossible for something to be more perfect than another. Also, perfect is a binary concept. Either something is perfect, or it is not.

Robust: Robust is a reserved word in some research fields, such as control theory, so use it with care. In control theory, a robust controller is usually capable of attenuating or rejecting disturbances. Nonetheless, robust might also have different, casual meanings, such as sturdy. Just ensure that the context is clear.

Proved/proven: Variations of the word prove should be used carefully, because anything that has been proven needs proof. For example, “(...) the system has been proven stable.” needs formal proof, such as one based on Lyapunov stability. If there is no proof of any sort, then this word might cause unnecessary confusion. For example, if the evidence is only qualitative, use “(...) the system has been shown useful.” instead of “(...) the system has been proven useful.”

Utilize: The word *utilize* is not just a fancier version of the word *use*. The expression “utilizing X” typically means “make use of; to turn X to practical use or account” and usually carries the particular connotation of “using X in a novel, practical, or profitable way.” [20]

[18] https://dictionary.cambridge.org/grammar/british-grammar/classic-or-classical
[19] https://ieee-tc-telerobotics.github.io/index.html
[20] https://www.merriam-webster.com/words-at-play/is-utilize-a-word-worth-using.

CHAPTER 3

Mathematical writing

There are good references for mathematical writing, and everyone aspiring to write any academic texts involving mathematics should read them. One of the best ones is the book by Franco Vivaldi [21], which is very pleasant to read and informative. An earlier version of this book is still available online.[1]

Below we summarize some of the main stylistic pitfalls and common mistakes. The list is far from comprehensive, and complying with those guidelines is the bare minimum to avoid readers from being distracted from the main points owing to bad mathematical writing. Sometimes, bad writing might even be syntactically or semantically incorrect and ambiguous.

3.1. Grammatical rules in mathematical expressions

Mathematical expressions are part of the text and should be punctuated accordingly. For example,

> *The relationship between the hypothenuse and the perpendicular sides of a right-angled triangle is given by*
>
> $$c^2 = a^2 + b^2,$$
>
> *where c is the hypothenuse's length, and a and b are the lengths of the sides adjacent to the right angle.*

is correct, whereas

> *The relationship between the hypothenuse and the perpendicular sides of a right-angled triangle is given by*
>
> $$c^2 = a^2 + b^2$$
>
> *Where c is the hypothenuse's length, and a and b are the lengths of the sides adjacent to the right angle.*

is not.

A good rule of thumb is to see if the mathematical expression would be punctuated if it was inline. For instance, the sentence below is grammatically incorrect:

> *Newton discovered that, if m is the mass of a body and a is its acceleration, then the resulting force is given by $F = ma$ This equation is known as Newton's second law.*

Clearly, there is a period missing after the equation. Therefore, if the equation is *displayed*, that is, separated from the text, it will only make sense if it is punctuated:

> *Newton discovered that, if m is the mass of a body and a is its acceleration, then the resulting force is given by*
>
> $$F = ma.$$
>
> *This equation is known as Newton's second law.*

In other words, a displayed equation is only a stylistic feature. Therefore, it should still obey grammatical rules.

3.1.1. Avoid starting sentences with mathematical expressions. Starting sentences with mathematical expressions is not only stylistically undesirable but might be very confusing, especially if the previous sentence ends with another mathematical expression. For example, instead of

> "*$\boldsymbol{x}$ is the task-space vector that represents the end-effector pose.*"

[1] http://www.thinkingwriting.qmul.ac.uk/sites/default/files/shared/files/Mathematical%20Writing%20for%20undergraduates%20Vivaldi.PDF

one should write

> *"The task-space vector $\boldsymbol{x}$ represents the end-effector pose."*

The latter avoids the problem of starting a sentence with a lower-case letter. If the mathematical expression is not a letter, it is even more awkward:

> "$\neg$ *is the symbol for the negation operator.*"

Instead, it is much better to write

> "*The negation operator is denoted by the symbol* $\neg$."

To see how starting sentences with mathematical expressions might be confusing, consider the following sentences:

> "*The negation operator is denoted by the symbol* $\neg$. $\wedge$ *is the conjunction operator that represents the logical operation* AND."

They become clearer if rewritten as

> "*The negation operator is denoted by the symbol* $\neg$*, whereas* $\wedge$ *is the conjunction operator that represents the logical operation* AND."

The previous sentences are quite simple. Hence, it is unlikely that people will be overly confused by the concatenation "$\neg$. $\wedge$." Nonetheless, this creates an unnecessary cognitive overload that is accentuated in a mathematically-intensive text.

But even simple sentences, although mathematically correct, might sound ambiguous due to bad writing. For instance:

> "*Consider the natural number 3. 4, which is the next one, is even.*"

At a first glance, it seems completely nonsensical because 3.4 is not a natural number, we do not know what its previous number should be, and a decimal number cannot be even. But then we realize that the number is not 3.4 because there is a space after the period! The same sentence, if written using words, not numerals, makes that clear:

> "*Consider the natural number three. Four, which is the next one, is even.*"

The previous sentence is perfectly fine, both mathematically and grammatically! We can still use numerals, and it suffices to use our rule of never starting a sentence with a mathematical symbol:

> "*Consider the natural number 3. The next one, 4, is even.*"

3.2. Multiline mathematical expressions

When using multiple mathematical expressions that must be together, such as in a multi-step derivation, a good LaTeX/LyX environment is the AMS align environment. For instance, suppose that we want to solve

$$\int_a^b a_0x^0 + a_1x^1 + a_2x^2 + a_3x^3 + a_4x^4\mathrm{d}x$$

while showing intermediate steps without any text between them. This often happens when subsequent steps follow immediately from previous ones without any need for further explanations. An inline derivation, such as $\int_a^b a_0x^0 + a_1x^1 + a_2x^2 + a_3x^3 + a_4x^4 = \int_a^b a_0x^0\mathrm{d}x + \int_a^b a_1x^1\mathrm{d}x + \int_a^b a_2x^2\mathrm{d}x + \int_a^b a_3x^3\mathrm{d}x + \int_a^b a_4x^4\mathrm{d}x = a_0x|_a^b + a_1\frac{x^2}{2}|_a^b + a_2\frac{x^3}{3}|_a^b + a_3\frac{x^4}{4}|_a^b + a_4\frac{x^5}{5}|_a^b = a_0(b-a) + a_1\frac{(b^2-a^2)}{2} + a_2\frac{(b^3-a^3)}{3} + a_3\frac{(b^4-a^4)}{4} + a_4\frac{(b^5-a^5)}{5} = \sum_{i=1}^5 a_{i-1}\frac{(b^i-a^i)}{i}$, is extremely clumsy. Putting each step of the derivation in displayed mode without aligning the equations helps in the visualization but is still awkward:

$$\int_a^b a_0x^0 + a_1x^1 + a_2x^2 + a_3x^3 + a_4x^4 = \int_a^b a_0x^0\mathrm{d}x + \int_a^b a_1x^1\mathrm{d}x + \int_a^b a_2x^2\mathrm{d}x + \int_a^b a_3x^3\mathrm{d}x + \int_a^b a_4x^4\mathrm{d}x$$

$$= a_0x|_a^b + a_1\frac{x^2}{2}\Big|_a^b + a_2\frac{x^3}{3}\Big|_a^b + a_3\frac{x^4}{4}\Big|_a^b + a_4\frac{x^5}{5}\Big|_a^b$$

$$= a_0(b-a) + a_1\frac{(b^2-a^2)}{2} + a_2\frac{(b^3-a^3)}{3} + a_3\frac{(b^4-a^4)}{4} + a_4\frac{(b^5-a^5)}{5}$$

$$= \sum_{i=1}^{5} a_{i-1}\frac{(b^i - a^i)}{i}.$$

One good way of writing the previous derivation is through the AMS align environment. Namely,

$$\begin{aligned}
\int_a^b a_0x^0 + a_1x^1 + a_2x^2 + a_3x^3 + a_4x^4 &= \int_a^b a_0x^0\mathrm{d}x + \int_a^b a_1x^1\mathrm{d}x + \int_a^b a_2x^2\mathrm{d}x + \int_a^b a_3x^3\mathrm{d}x + \int_a^b a_4x^4\mathrm{d}x \\
&= a_0x\Big|_a^b + a_1\frac{x^2}{2}\Big|_a^b + a_2\frac{x^3}{3}\Big|_a^b + a_3\frac{x^4}{4}\Big|_a^b + a_4\frac{x^5}{5}\Big|_a^b \\
&= a_0(b-a) + a_1\frac{(b^2-a^2)}{2} + a_2\frac{(b^3-a^3)}{3} + a_3\frac{(b^4-a^4)}{4} + a_4\frac{(b^5-a^5)}{5} \\
&= \sum_{i=1}^{5} a_{i-1}\frac{(b^i - a^i)}{i}.
\end{aligned}$$

Sometimes, one might want to group different mathematical expressions that do not result from a derivation. For example, suppose that we wanted to list three trigonometric identities: $\cos^2 x + \sin^2 x = 1$, $\cos(a+b) = \cos a\cos b - \sin a \sin b$, and $\sin(a+b) = \sin a\cos b + \sin b\cos a$. In the same way that we use punctuation marks while listing them inline, we need to use punctuation marks when using them in displayed mode:

$$\begin{aligned}
\cos^2 x + \sin^2 x = 1&, \\
\cos(a+b) &= \cos a\cos b - \sin a\sin b, \\
\sin(a+b) &= \sin a\cos b + \sin b\cos a.
\end{aligned}$$

However, suppose that $a = b = \pi$. In the same way that $\cos(2\pi) = \cos(\pi+\pi), = \cos\pi\cos\pi - \sin\pi\sin\pi, = 1$ is syntactically wrong because of the comma before the equal sign, so is

$$\begin{aligned}
\cos(2\pi) &= \cos(\pi+\pi), \\
&= \cos\pi\cos\pi - \sin\pi\sin\pi, \\
&= 1.
\end{aligned}$$

The attentive reader should have realized by now that the punctuation rules are the same for both inline and displayed equations because they are exactly the same thing.

3.3. Use of lengthy subscripts and superscripts

When using lengthy (three or more characters) subscripts and superscripts, especially when they represent text, it is a good idea to write them in upright face to increase readability. For example, although there is nothing syntactically wrong with $\mathcal{F}_{world}$, it looks much better if we write it as $\mathcal{F}_{\text{world}}$. This is because letters in math mode have different typography, usually for the reason that they are meant to represent constants and variables, not text. For instance, 'abc' and 'xyz' become abc and xyz in math mode.

To write text in math mode within LaTeX/LyX, one can use either `\text` or `\mathrm`.

3.4. Variable naming

It is usually more elegant[2] and more compact to use single letters than words to denote variables. For example, the magnitude of the linear velocity v equals the product of the angular velocity ω and the radius r of the circular motion; that is,

$$v = \omega r, \tag{3.4.1}$$

which is much better than

$$\text{linear velocity} = \text{angular velocity} \times \text{radius}. \tag{3.4.2}$$

Eq. (3.4.2) often appears in more elementary texts, and are not the best choice for academic texts.

[2]This is a subjective statement but mathematicians and more mathematically-inclined engineers agree on this.

3.5. Mathematical notation

"Novelty in academia is something we strive for, but this is not the place to be creative." — Murilo M. Marinho, to countless students that came up with their own mathematical notation, usually utterly indecipherable to others.

Mathematical notation is something that evolves, or at least should evolve, together with a research group. A stable mathematical notation, as long as it is correct and well thought, allows readers of a set of papers to have considerably less cognitive load. However, one should not read into this and believe that the notation that their group uses is the only correct one (we are looking at you, Reviewer #2).[3]

When the notation required in a new manuscript is not present in prior works and not established in one's research group, referring to mathematical guides, such as Vivaldi's [**21**], and related works is often a good strategy. Nonetheless, borrowing another work's faulty notation should never be an excuse to use bad notation (refer to Section 1.4.2).

Furthermore, standard notation is always preferred over nonstandard ones. For example, different people might define the set $\mathbb{R}^+$ as

$$\mathbb{R}^+ \triangleq \{x \in \mathbb{R} : x > 0\}$$

or

$$\mathbb{R}^+ \triangleq \{x \in \mathbb{R} : x \geq 0\}.$$

To avoid confusion, notations like the ones above can be either formally defined or explained textually (e.g., "where $\mathbb{R}^+$ is the set of non-negative real numbers"). However, those definitions can be avoided if a universally accepted convention is used, such as $[0, \infty)$ for the set of *non-negative* real numbers or $(0, \infty)$ for the set of *positive* real numbers.

In any case, there are two golden rules when defining new symbols [**21**]:

(1) Do not introduce unnecessary symbols.
(2) Define every symbol before using it.

3.6. Common mistakes

3.6.1. Referring to mathematical expressions other than equalities as equations. An equation is *always* determined by an equality. An equation results from the process of *equating* things, which means making those things equal! Therefore, referring to mathematical expressions other than equalities as equations is wrong. For example, saying that

"*according to the equation $x \leq 0$, the variable x is always nonpositive*"

is wrong because $x \leq 0$ is an inequality. Therefore, the correct is

"*according to the **inequality** $x \leq 0$, the variable x is always nonpositive.*"

The same reasoning applies for other mathematical expressions, such as inclusions (e.g., $a \in A$), implications ($a \implies b$), and other equivalences ($x \iff y$).

3.6.2. Misuse of $\to$ (to) and $\mapsto$ (maps to). The symbol used to map the domain to the codomain of a function should be $\to$ instead of $\mapsto$ [21]. The latter is used to map specific elements of the set. For example,

$$f : \mathbb{R} \to \mathbb{R} \qquad x \mapsto -x$$

defines the function $f(x) = -x$.[4] Therefore, writing $g : \mathbb{R} \mapsto \mathbb{R}$ is wrong, albeit it is a relatively common mistake.

[3] Members of our groups are impelled to use the notation that our groups have in common. We even make LyX macros available! Needless to say, if one is not a member of our group, they should always use the notation established in their group whenever possible.
[4] For more examples, see https://math.stackexchange.com/questions/936558/use-of-mapsto-and-to.

3.6.3. Wrong usage of the $\arg\min$ **output.** Given $f : X \to Y$, the $\arg\min$ map is defined as

$$\arg\min_{x\in S} f(x) \triangleq \{x \in S : \forall s \in S, f(x) \leq f(s)\}.$$

Therefore, the output of $\arg\min$ is a *set* containing all elements in $S \subseteq X$such that f attains its minimum value. For example,

$$\arg\min_{x} (x+1)^2(x-3)^2 = \{-1, 3\}$$

Analogously,

$$\arg\min_{x} |x-\pi| = \{\pi\},$$

which is a *singleton*, that is, a set with only one element. Therefore,

$$y = \arg\min_{x} |x-\pi| \implies y = \{\pi\} \tag{3.6.1}$$

whereas

$$y \in \arg\min_{x} |x-\pi| \implies y = \pi. \tag{3.6.2}$$

A common mistake is to use (3.6.1) and (3.6.2) interchangeably. However, $\{\pi\} \neq \pi$ because $\{\pi\}$ is a set whereas π is a number.

CHAPTER 4

Graphs, figures, tables, and illustrations

4.1. What graphs should I put in my article/report/thesis?

Graphs are used to support one's claims and help the reader understand the techniques being proposed or presented. Therefore, the first question one needs to consider is: what is needed to show to convince the reader that the proposed technique is working as designed?

For example, to show that a manipulator robot can drive its end-effector toward the desired set-point, one needs to show the time response of the error function norm. If the goal is to show that the robot respects constraints, a good way is to present a graph illustrating that. If the objective is to show that the control signal has a particular behavior, it is a good idea to show the time evolution of the control inputs throughout the simulation, etc.

4.2. Graphs and figures that I should *not* include in my article/report/thesis: the infamous Nightmare-Fuel Figures (NFFs)

Unlike the writer of academic texts, such as theses, dissertations, or papers, readers did not spend countless hours looking, operating, and reflecting on the experimental setup and data of the research being reported. For effective dissemination of the work, clear understanding of the experimental setup is paramount. Therefore, the quality of figures and illustrations is not only a matter of aesthetics. For instance, poorly prepared and presented setup images such as the ones in Fig. 4.2.1 serve only to nourish nightmares in supervisors and coauthors. They effectively reduce the quality of the work to the extreme where not having an image would have been better. Although many readers will chuckle when seeing those figures and think, "Oh, it's such an exaggeration! Nobody will ever do that, especially at the postgraduate level," we can assure the reader that we have seen many cases like these. In contrast, some readers might not even recognize the problem of those figures, especially the second one. So, let us unpack the many problems with those figures.

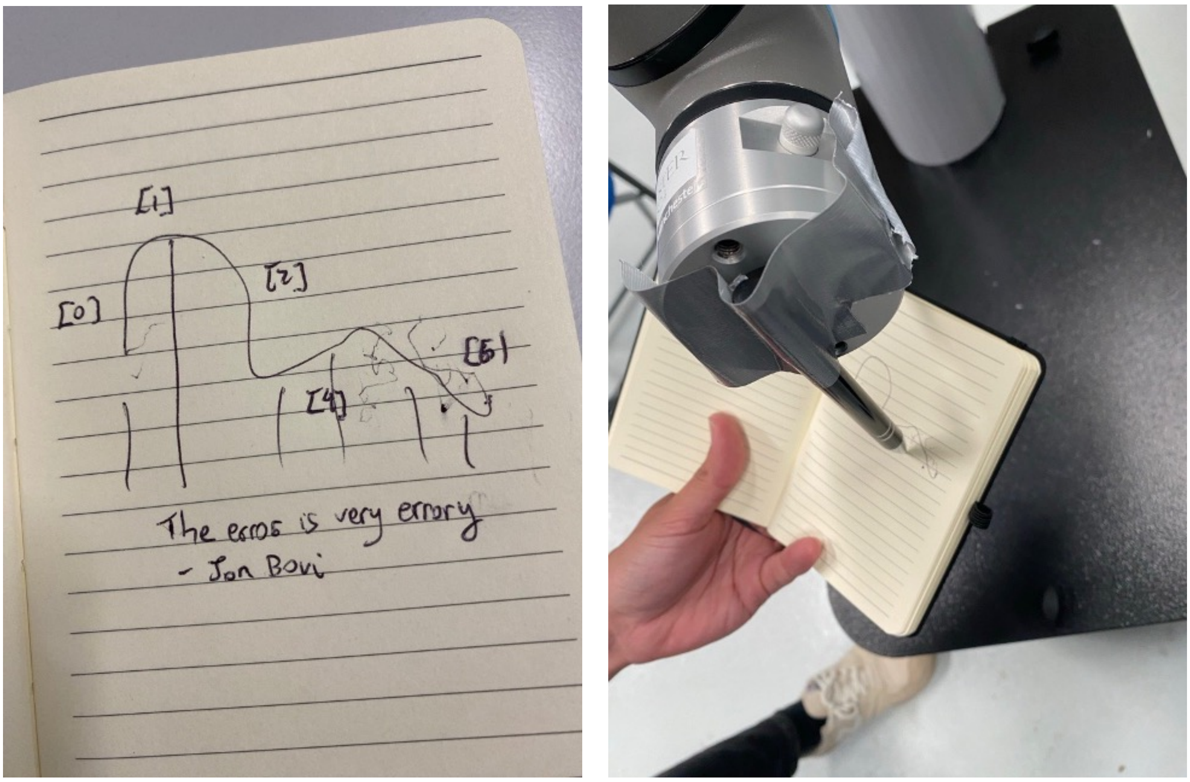
Fig. 4.2.1a contains a hand-drawn plot on a notebook. The first question that naturally arises is: why would one hand draw a plot on a *notebook* to put in a final academic text when computers are very affordable with many professional-plotting software available, including free and open-source? Unless one is very skilled in technical drawing and no other option is available, one should use a professional-grade software such as MATLAB,[1] Gnuplot,[2] or Matplotlib.[3] Moreover, the image is not adequately cropped and is slanted. Finally, although the illumination is not terribly bad, shadows make it even more amateurish.

On the other hand, Fig. 4.2.1b shows a pen attached to a manipulator end-effector while the robot draws on a notebook. The very first problem with this figure is that it does not look professional. One can hardly recognize the manipulator, there is a person holding the notebook (why?!), their foot is visible on the background, and the photo lacks proper annotations. The next sections aim at bringing some sanity and introduce guidelines for appropriately designing and presenting professional-looking figures.

4.3. General instructions

In contrast with NFFs, proper figures are used to help conveying useful information. *If something can be effectively explained without figures, there is no point in using them.* On the other hand, if they are confusing,

[1] https://uk.mathworks.com/products/matlab.html
[2] http://www.gnuplot.info/
[3] https://matplotlib.org/



(A) How **not** to show a plot. (B) How **not** to show experimental setups.

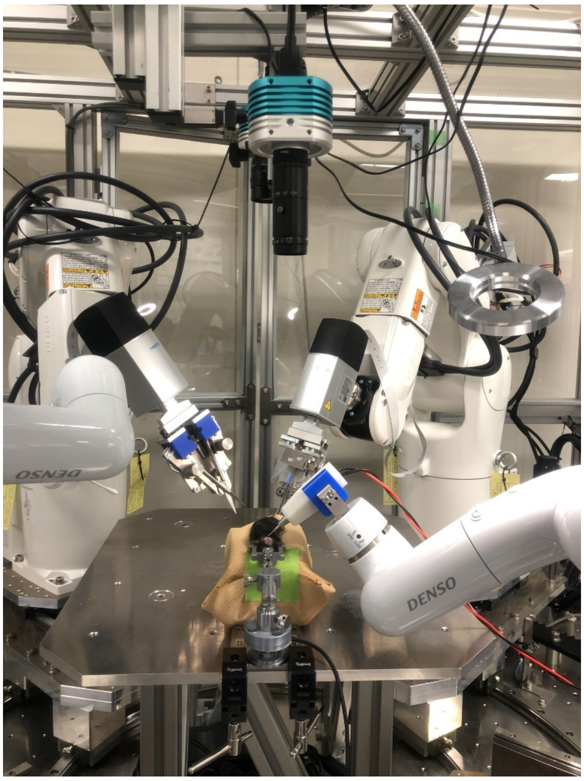
FIGURE 4.2.1. Examples of how not to present results and experimental setups. We're not exaggerating; we've seen such figures (even worse) in academic reports.

they might cause more harm than good. This means that figures should be carefully thought, and sometimes it takes a **lot** of time to create them. To better connect the discussion in the text with the figures, it is useful to annotate them. This includes illustrations and graphs. A well designed, impactful figure can enhance someone's understanding (and appreciation) of one's work, whereas a bad figure will certainly have the opposite effect.

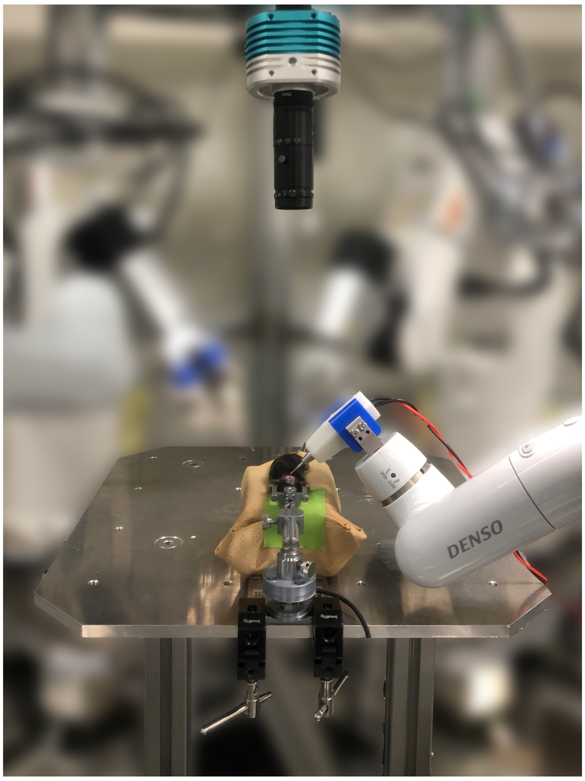
As general instructions, let us refer to Fig. 4.3.1, which shows a complex experimental setup that is intrinsically cluttered. First, it is fundamental to have a good photo to begin with, like in Fig. 4.3.1a. Despite the complexity of the experimental setup, which contains many robotic manipulators and sensors, the photo captures the scene from a nice angle, includes all relevant equipment, and the illumination is adequate with no shadows in the foreground. Then, the background elements should be removed to focus on the work's content, see Fig. 4.3.1b. When working with complex setups, consider blurring instead of removing the background because entirely removing it can make photos unnatural. This is because it is difficult to remove background elements perfectly and blurring is more forgiving. Furthermore, even when the background is accurately removed, some reviewers might sometimes be confused and think that the figure was generated using computer graphics. Then, annotations should be added to explain the elements in the photo from the point of view of someone who's seeing it for the first time, see Fig. 4.3.1c. Lastly, empty space should be occupied with additional details to increase content delivery and quality, see Fig. 4.3.1d. In this partially censored image, the close-up on the object to be drilled, a mouse's skull, shows what the robot is doing without having to resort to a second image. This makes effective use of space, which is particularly critical in journal and conference articles, where the number of pages is usually limited.

4.4. Size and arrangement

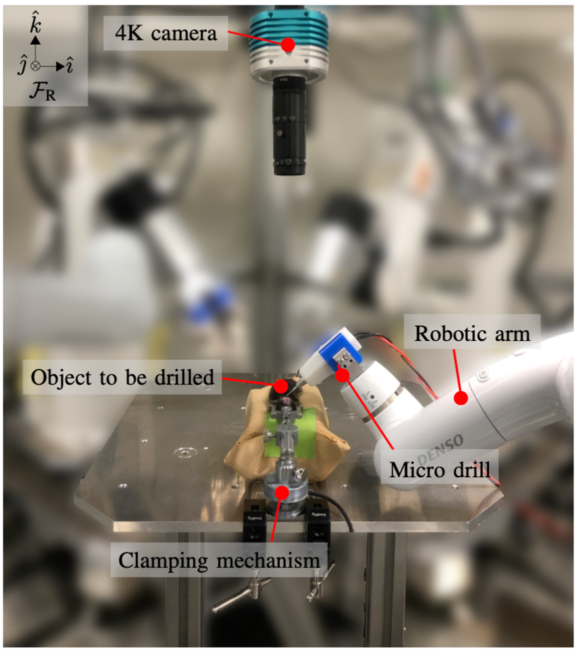
It is common for papers to have a page limit, which constrains the size and number of figures one can include in the final text. Nonetheless, figures should be clear and of appropriate size, otherwise they become



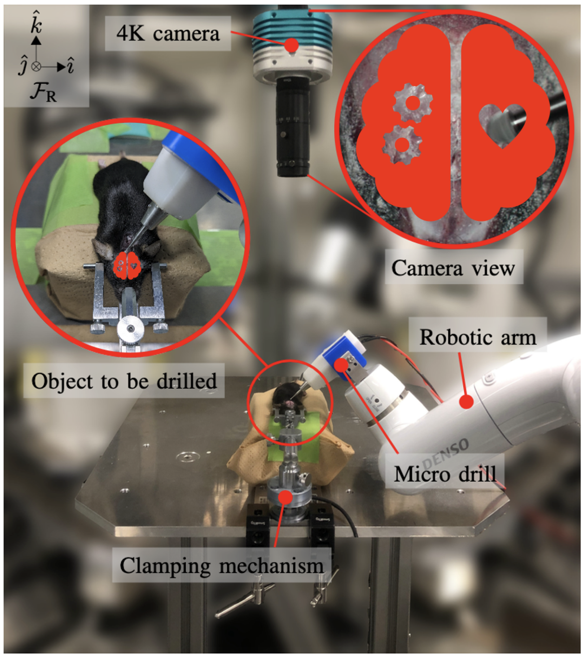
(A) The environment needs to be clean and organized before taking the photo to show everything with minimal editing.



(B) Remove the background and all unimportant elements in the photo to focus on what must be described. Consider blurring instead of removing the background for complex setups because entirely removing it can make photos unnatural.



(C) Annotate to clarify what exactly the image must convey. Do not use arrows unless they indicate direction. Be sure to use colors for lines that stand out. Those can be different depending on what the original photo contains.



(D) The golden rule is that empty space in figures is waste. Add close-ups and different views to increase content delivery and quality.

FIGURE 4.3.1. The making of a good setup figure. The final figure is available in [22].

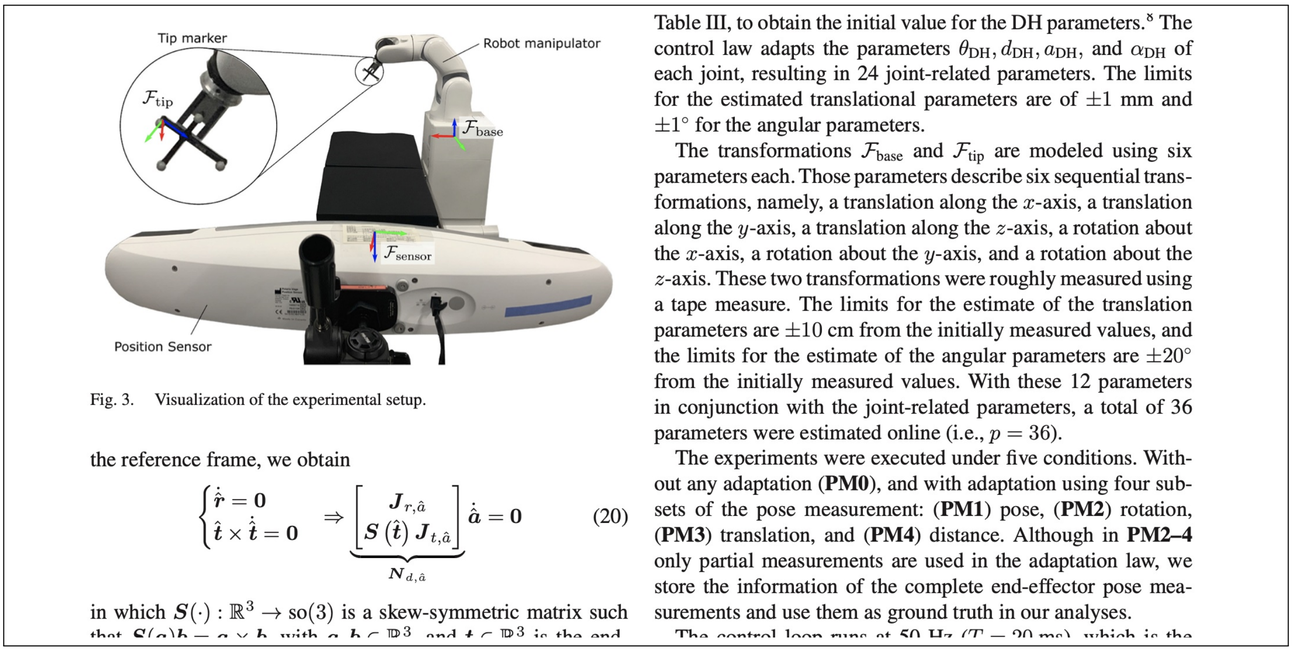


Fig. 3. Visualization of the experimental setup.

the reference frame, we obtain

$$\begin{cases} \dot{\hat{\boldsymbol{r}}} = \boldsymbol{0} \\ \hat{\boldsymbol{t}} \times \dot{\hat{\boldsymbol{t}}} = \boldsymbol{0} \end{cases} \Rightarrow \underbrace{\begin{bmatrix} \boldsymbol{J}_{r,\hat{a}} \\ \boldsymbol{S}\left(\hat{\boldsymbol{t}}\right) \boldsymbol{J}_{t,\hat{a}} \end{bmatrix}}_{\boldsymbol{N}_{d,\hat{a}}} \dot{\hat{\boldsymbol{a}}} = \boldsymbol{0} \tag{20}$$

in which $\boldsymbol{S}(\cdot) : \mathbb{R}^3 \to \mathrm{so}(3)$ is a skew-symmetric matrix such

Table III, to obtain the initial value for the DH parameters.[8] The control law adapts the parameters $\theta_{\text{DH}}, d_{\text{DH}}, a_{\text{DH}}$, and α_{DH} of each joint, resulting in 24 joint-related parameters. The limits for the estimated translational parameters are of ± 1 mm and $\pm 1°$ for the angular parameters.

The transformations $\mathcal{F}_{\text{base}}$ and $\mathcal{F}_{\text{tip}}$ are modeled using six parameters each. Those parameters describe six sequential transformations, namely, a translation along the x-axis, a translation along the y-axis, a translation along the z-axis, a rotation about the x-axis, a rotation about the y-axis, and a rotation about the z-axis. These two transformations were roughly measured using a tape measure. The limits for the estimate of the translation parameters are ± 10 cm from the initially measured values, and the limits for the estimate of the angular parameters are $\pm 20°$ from the initially measured values. With these 12 parameters in conjunction with the joint-related parameters, a total of 36 parameters were estimated online (i.e., $p = 36$).

The experiments were executed under five conditions. Without any adaptation (**PM0**), and with adaptation using four subsets of the pose measurement: (**PM1**) pose, (**PM2**) rotation, (**PM3**) translation, and (**PM4**) distance. Although in **PM2–4** only partial measurements are used in the adaptation law, we store the information of the complete end-effector pose measurements and use them as ground truth in our analyses.

FIGURE 4.4.1. Example of an annotated figure with the same width as the column in a double-column paper [14].

useless. On the other hand, some academic works such as reports do not have page limits or those are very generous, which means figures can be as large as the text width or as big as the whole page length.

Choosing the right size have different considerations, such as readability, aesthetics, and available space. Therefore, in double column documents, usually column figures should have the same width as the column, as illustrated in Fig. 4.4.1. Sometimes, however, the whole column width might not be sufficient, and the solution is to use a figure that spans both columns, such as in Fig. 4.4.2.

Pro tip: When defining the size of figures in LaTeX/LyX, instead of using absolute values (e.g., width equal to 6 cm) or directly changing the figure scale (e.g., 70% of the original width), it is much better to define the width or length as a function of the column or text size. That way, even if the paper size or the column width changes, the figure will still maintain the same ratio with respect to the column or text width.

4.5. Tables

When designing tables, authors should focus on the data and how to better present them. Borders should be used sparingly and never get in the way. Data labels should be as concise and self-explanatory as possible, and units should be included.

Let us consider Table 1, which was generated with borders around all cells with no care about format and presentation. Do not think much about the data because it was completely made up. The purpose is to focus on presentation issues. The table has descriptive labels, as readers should be familiar with most acronyms on the first column, and the first row clearly shows that tracking, computational time, and control effort are being evaluated. However, no units are presented, making it hard to evaluate the impact of each technique. For example, if the tracking error is related to an aerial robot traveling ten kilometers and the error units is in centimeters, who cares if the average tracking errors for the PID and LQR controllers are 5.7 cm and 2.7 cm, respectively? They would be essentially equivalent. However, if the units are also in kilometers, a tracking error of 2.7 km is clearly an improvement over 5.7 km across a trajectory of ten kilometers. Lastly, the data is not grouped optimally. So, let us first improve include units and improve the borders.

Table 2 is much cleaner and contain relevant units, but it is far from ideal. The labels are lengthy and not grouped appropriately, making the data unnecessarily hard to analyze. To improve it, we can group the minimum, average, and maximum quantities for each metric. The result is shown in Table 3, which is clearly much neater than Table 2 because readers can focus on a given metric more easily, as metrics are grouped

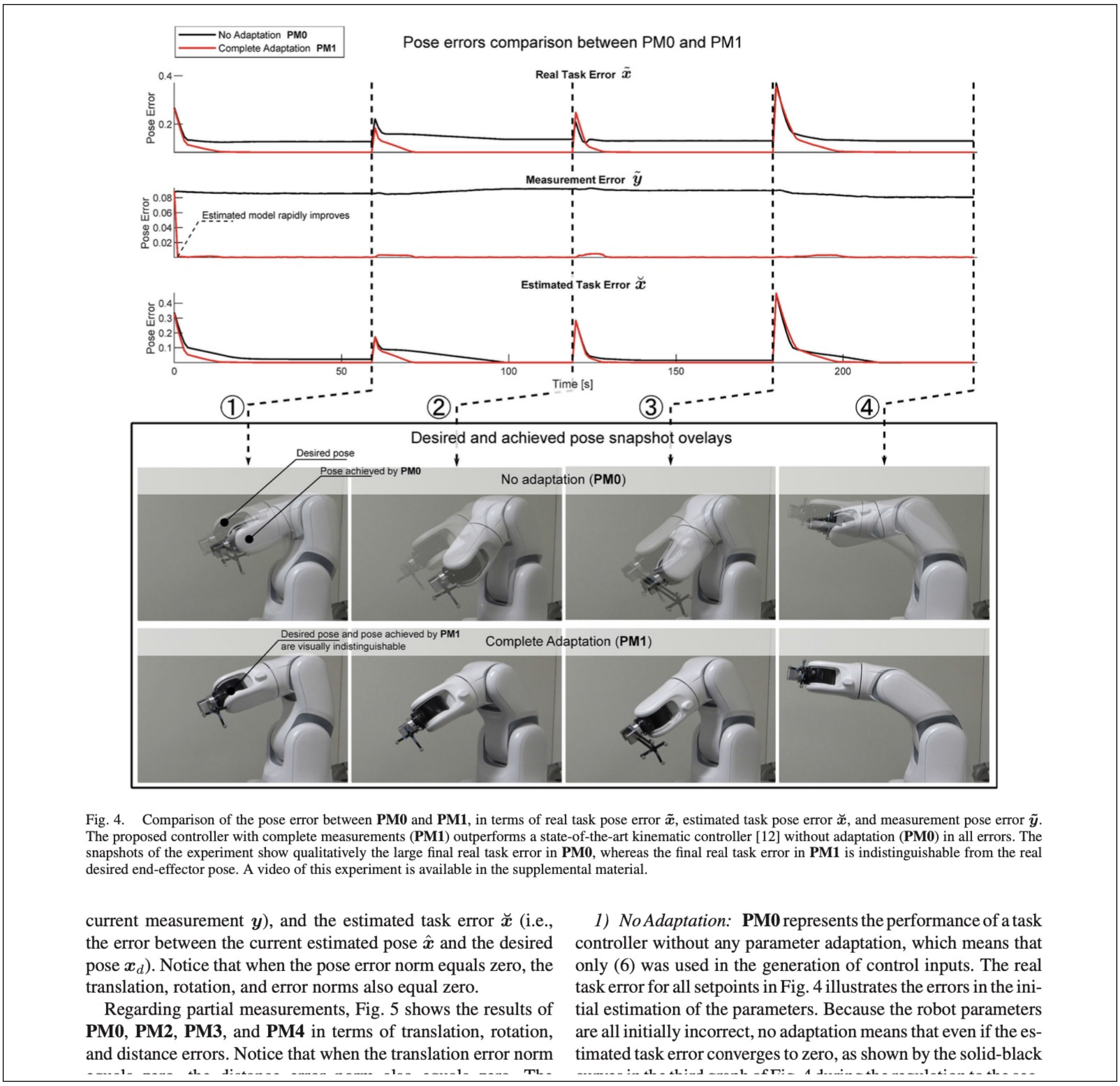


Fig. 4. Comparison of the pose error between **PM0** and **PM1**, in terms of real task pose error $\tilde{x}$, estimated task pose error $\check{x}$, and measurement pose error $\tilde{y}$. The proposed controller with complete measurements (**PM1**) outperforms a state-of-the-art kinematic controller [12] without adaptation (**PM0**) in all errors. The snapshots of the experiment show qualitatively the large final real task error in **PM0**, whereas the final real task error in **PM1** is indistinguishable from the real desired end-effector pose. A video of this experiment is available in the supplemental material.

current measurement y), and the estimated task error $\check{x}$ (i.e., the error between the current estimated pose $\hat{x}$ and the desired pose x_d). Notice that when the pose error norm equals zero, the translation, rotation, and error norms also equal zero.

Regarding partial measurements, Fig. 5 shows the results of **PM0**, **PM2**, **PM3**, and **PM4** in terms of translation, rotation, and distance errors. Notice that when the translation error norm

1) No Adaptation: **PM0** represents the performance of a task controller without any parameter adaptation, which means that only (6) was used in the generation of control inputs. The real task error for all setpoints in Fig. 4 illustrates the errors in the initial estimation of the parameters. Because the robot parameters are all initially incorrect, no adaptation means that even if the estimated task error converges to zero, as shown by the solid-black

Figure 4.4.2. Example of an annotated figure with the same width as the column in a double-column paper [14].

together, and labels are much shorter and informative. However, if the reader wants to know which technique is the best one for a particular metric, they still need to compare them one by one. A much better option is to highlight the quantities related to the best method for each metric. This is shown in Table 4.

4.6. General recommendations

(1) Figures and tables **must** be discussed and referenced in the main text.
(2) Avoid using above, below, and similar adverbs to refer to figures, tables, and alike. Due to formatting, those floating environments usually may be placed in a different page, such that those adverbs of place become inconsistent (a figure on another page is *not* above the current text!). Use their numbers instead with appropriate cross-references; that is, do not number them manually.

4.7. Common mistakes when presenting figures

4.7.1. Wrong scale and inadequate captions. Suppose a paper proposes a new mathematical model for a four-DoF robot. In the results section, the authors qualitatively compare the predicted output of the new

Table 1. Cluttered table with lots of unnecessary borders, no units, and with suboptimal grouping of relevant quantities.

	Minimum tracking error	Average tracking error	Maximum tracking error	Minimum computational time	Average computational time	Maximum computational time	Minimum control effort	Average control effort	Maximum control effort
PID	4.2	5.7	17.8	0.1	0.15	0.18	103.2	202.7	309.1
LQR	1.2	2.7	8.1	1.0	1.1	1.3	3.5	10.2	18.3
MPC	3.3	3.5	8.0	2.7	3.8	4.4	7.9	13.5	27.2
DDMPC	3.5	3.7	8.2	4.7	7.8	10.4	17.8	33.3	57.9
QP	3.9	4.1	9.9	1.3	1.7	1.9	15.2	37.1	42.7
Adaptive QP	3.6	3.8	8.9	1.6	1.9	2.3	14.1	28.9	35.2

Table 2. Table with lengthly labels and suboptimal grouping of relevant quantities.

	Minimum tracking error (m)	Average tracking error (m)	Maximum tracking error (m)	Minimum computational time (s)	Average computational time (s)	Maximum computational time (s)	Minimum control effort (N · m)	Average control effort (N · m)	Maximum control effort (N · m)
PID	4.2	5.7	17.8	0.1	0.15	0.18	103.2	202.7	309.1
LQR	1.2	2.7	8.1	1.0	1.1	1.3	3.5	10.2	18.3
MPC	3.3	3.5	8.0	2.7	3.8	4.4	7.9	13.5	27.2
DDMPC	3.5	3.7	8.2	4.7	7.8	10.4	17.8	33.3	57.9
QP	3.9	4.1	9.9	1.3	1.7	1.9	15.2	37.1	42.7
Adaptive QP	3.6	3.8	8.9	1.6	1.9	2.3	14.1	28.9	35.2

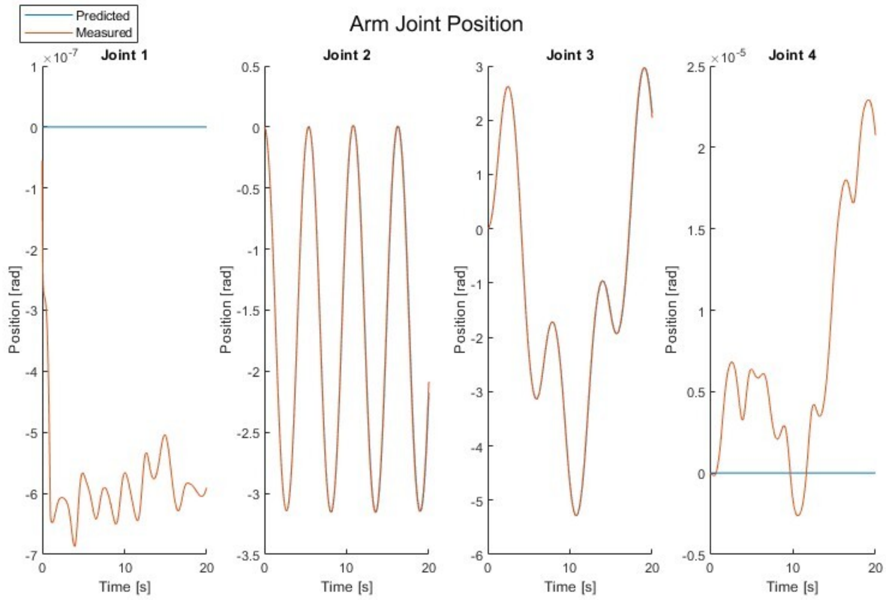
Table 3. Table with appropriate labels and adequate grouping of relevant quantities.

	Tracking error (m)			Computational time (s)			Control effort (N · m)		
	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
PID	4.2	5.7	17.8	0.1	0.15	0.18	103.2	202.7	309.1
LQR	1.2	2.7	8.1	1.0	1.1	1.3	3.5	10.2	18.3
MPC	3.3	3.5	8.0	2.7	3.8	4.4	7.9	13.5	27.2
DDMPC	3.5	3.7	8.2	4.7	7.8	10.4	17.8	33.3	57.9
QP	3.9	4.1	9.9	1.3	1.7	1.9	15.2	37.1	42.7
Adaptive QP	3.6	3.8	8.9	1.6	1.9	2.3	14.1	28.9	35.2

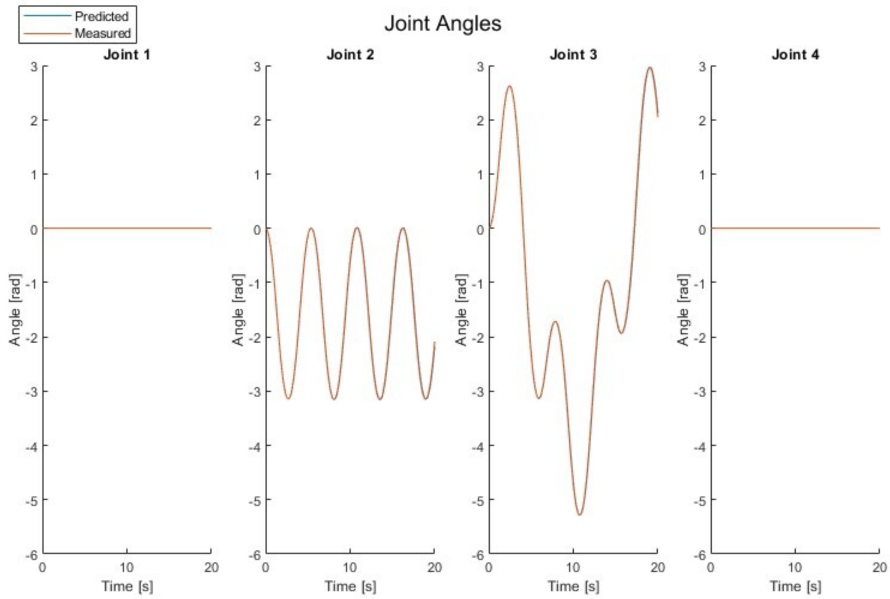
Table 4. Final table with no unnecessary, distracting borders, with appropriate labels and adequate grouping of relevant quantities, and highlighted quantities indicating the best method for each metric.

	Tracking error (m)			Computational time (s)			Control effort (N · m)		
	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
PID	4.2	5.7	17.8	**<u>0.1</u>**	**<u>0.15</u>**	**<u>0.18</u>**	103.2	202.7	309.1
LQR	**<u>1.2</u>**	**<u>2.7</u>**	8.1	1.0	1.1	1.3	**<u>3.5</u>**	**<u>10.2</u>**	**<u>18.3</u>**
MPC	3.3	3.5	**<u>8.0</u>**	2.7	3.8	4.4	7.9	13.5	27.2
DDMPC	3.5	3.7	8.2	4.7	7.8	10.4	17.8	33.3	57.9
QP	3.9	4.1	9.9	1.3	1.7	1.9	15.2	37.1	42.7
Adaptive QP	3.6	3.8	8.9	1.6	1.9	2.3	14.1	28.9	35.2

model with the measured values from a realistic simulator by superimposing the curves from the model and the simulator, as shown in Fig. 4.7.1a. At a first glance, it seems that the predicted and measured outputs for the second and third joints match exactly, whereas they are very distinct for the first and fourth joints. However, an attentive reader will notice that the scales are very different, and probably the "mismatch" in the first and fourth joints is the result of measurement noise. Moreover, the labels on the vertical axis and the title are



(A) Misleading figure. Can you spot where the problems are?



(B) Same data as in Fig. 4.7.1a, but with a different presentation. Notice that the predicted and measured values match closely so that both curves are superimposed in all plots.

FIGURE 4.7.1. Same data, different presentation.

unnecessarily confusing because they refer to "positions" but the units are radians, suggesting that all joints are revolute.

Fig. 4.7.1b presents the same data shown in Fig. 4.7.1a,[4] but the scale are the same for all joints, showing that the predicted output using the new mathematical model accurately matches the measured values from the realistic simulator. Moreover, the labels on the vertical axes clearly indicate that those joints are all revolute, as they refer to angles and their corresponding units, radians. Those figures can be aesthetically improved even further by changing their proportion, notably by reducing their height such that they occupy less vertical space without any loss of relevant information.

[4]Those figures were kindly generated by Hangyeol Go. We'll include this information in an appropriate Acknowledgements section in due time.

CHAPTER 5

References

5.1. How many references should I put in my article/report/thesis?

See Section 2.4.11 for a comprehensive discussion about references and citations.

5.2. Tips and tricks when using author-year citations together with a numeric referencing style

Sometimes, we want to use numeric referencing citations, such as IEEETran, but also mention the authors of a given reference. For example, suppose we want to cite the INCOMPLETE GUIDE [1] but also explicitly indicate the authors. Therefore, we could say that Adorno and Marinho are writing the INCOMPLETE GUIDE [1] to help not only their students but also anyone who wants to write an academic text in the robotics field.

If LaTeX/LyX is used—and we could not emphasize enough that it should!—there is no straightforward option[1] to do it automatically in the same way as when using author-year referencing styles such as the Chicago style.

Therefore, authors should follow some basic rules depending on the number of authors:

(1) If there is just one author, refer to their last surname. For example, "Vivaldi [21] wrote a very good book on mathematical writing." When there are two surnames connected by a hyphen, we use both. For example, "Herculano-Houzel is a Brazilian neuroscientist who argues 'in favor of a view of cognitive abilities that is centered on absolute numbers of neurons, rather than on body size or encephalization' [8]."

(2) If there are exactly two authors, refer to their last surnames. For example, "Adorno and Marinho [1] claim that LyX is more general than LaTeX in the same way C++ is more general than C."

(3) For three or more authors, refer to the first author's last surname followed by *et al.*, which must be italicized. This is because *et al.* is an abbreviation of the Latin expression "*et alli,*" which means "and others." For example, "Marinho *et al.* [15] proposed a technique, called Vector Field Inequalities, in which nonlinear constraints in the robot configuration can be transformed into linear constraints in the control inputs."

Notice that if any of the authors use a composite surname such as Herculano-Houzel, we should count it as just one surname. For example, "Herculano-Houzel and Lent [9] discovered that glial cells are not the majority in the rat brain."

[1] At least, there is no viable option that *we* are aware of. If anyone knows how to do it automatically without having to resort to any hacking mechanism, please let us know.

CHAPTER 6

Good practices in LaTeX and LyX

6.1. Using builtin mathematical symbols

Some mathematical symbols are builtin in LaTeX (and consequently, available in LyX) and the corresponding commands should be used. For example, for trigonometric functions, one should use $\cos\alpha$ instead of $cos\alpha$. For limits, $\lim_{t\to\infty}$ should be used instead of $lim_{t\to\infty}$, etc. Besides having a much better aesthetics, using the builtin commands enables LaTeX/LyX to handle those symbols appropriately. For example, when using displayed mathematical expressions, we obtain

$$\lim_{t\to\infty}$$

when typing `\lim_{t\to\infty}`. However, when typing `lim_{t\to\infty}`, we obtain

$$lim_{t\to\infty},$$

which is typographically incorrect.

Table 1 presents a non-exhaustive list of some common overlooked builtin mathematical symbols and how to type them correctly in LaTeX/LyX.

TABLE 1. Non-exhaustive list of some common overlooked builtin mathematical symbols.

	How it looks without using the builtin mathematical commands	**How it looks when using builtin mathematical commands**	**LaTeX command**
Trigonometric functions	$arctan(x)$	$\arctan(x)$	`\arctan(x)`
	$cos(x)$	$\cos(x)$	`\cos(x)`
	$cosh(x)$	$\cosh(x)$	`\cosh(x)`
	$sin(x)$	$\sin(x)$	`\sin(x)`
Functions used in optimization problems	$argminf(x)$	$\arg\min f(x)$	`\arg\min f(x)`
	$maxf(x)$	$\max f(x)$	`\max f(x)`
Limits, logarithms, and exponentials	$expx$	$\exp x$	`\exp x`
	$logx$	$\log x$	`\log x`
	lnx	$\ln x$	`\ln x`
	$limx$	$\lim x$	`\lim x`
Binary operations	$\boldsymbol{uxv} = \boldsymbol{w}$	$\boldsymbol{u} \times \boldsymbol{v} = \boldsymbol{w}$	`u \times v = w`
	$x * y = z$	$x \cdot y = z$	`x \cdot y = z`

CHAPTER 7

General advice

Our general advice here aims to guide people according to common academic etiquette and generally accepted good practices. Nonetheless, different groups and supervisors might have different styles and follow different research philosophies. Therefore, the advice below should not replace what students and supervisors agree upon or what their institutions determine.

7.1. Interacting with supervisors

To convince your audience or enable others to help or engage with you intellectually, you must make the information accessible and as easy as possible to digest. This is also applicable when talking to your peers and supervisors. For instance, when communicating with your supervisor:

(1) Use the mechanisms for communication that your supervisors have put in place. Remember that their relationship with you is one-to-many; while you have one or two supervisors, they have many students. Therefore, they probably have an efficient mechanism for communication in place to maintain their sanity and ensure students are served promptly. Thus, use the mechanism they suggested (e.g., Slack, emails, etc.). It is much easier and expected for you to adapt to their style than the opposite.

(2) When emailing supervisors, be concise and straight to the point. It is not uncommon for principal investigators and supervisors to spend two hours per day answering emails, sometimes even more. They do not have time to read long, poorly-written emails. If your email is important but will take time to deal with, your supervisor will likely put it at the end of his/her long list of equally or even more important emails.

(3) Be honest and transparent about your research. Concealing something from your supervisor and collaborators is unproductive, potentially unethical, and might worsen the problem (unhappy supervisor, wasted time, loss of trust, etc.)

(4) If you can get *trustworthy* information directly from colleagues rather than your supervisor, do it whenever possible. It is much more effective if you get from your supervisor what you cannot get from anyone else. Their time is scarce, and their expertise and experience are unique. For example, asking supervisors for information about administrative procedures that you know for a fact other students are familiar with is a missed opportunity for you to engage with them about what matters in your research or career. However, remember not to use reliance on others as an excuse for making wrong decisions (see Section 1.4.2).

(5) When asking questions, the number one rule of thumb is: "Vague questions will likely result in vague answers." Therefore, when asking questions, one should contextualize it succinctly and ask it precisely. Unnecessary details will take the focus from the relevant point, too little detail will make the question vague. Finding the right balance gets easier with time and experience. Nonetheless, sufficiently thinking about how to ask a question before meeting with one's supervisor or before writing an email will be immensely beneficial for everyone. It will help students organize their ideas, which might even lead them to find the solution themselves. Also, it will maximize the chances of their supervisors understand the question, preventing unnecessary confusion and frustration for all parties involved. Lastly, it follows the same principle applied to writing: people's time is precious and we must respect it.

(6) Your supervisors generally are not your friends, even when they are approachable and address you on a first-name basis. Like it or not, there is an intrinsic hierarchy and power dynamics in the supervisor-supervisee relationship that might be challenging to grasp fully, and different supervisors and students deal with them differently. Your supervisors will usually wear different hats, such as the one of a mentor, sometimes of a boss or a senior colleague. Therefore, when unsure how to address or interact with them, the safest approach is to ask how they want to do it. That way, you will avoid many uncomfortable situations, especially when people come from different cultural backgrounds.

(7) When asked to do some tasks in the context of your research, make sure you understand the requests and fulfill them. A classic example is when supervisors review their students' papers and request amendments to some systematic errors, such as a grammar mistake made across the whole text. Because those errors are systematic, supervisors might point out just a handful without being exhaustive. However, they expect you to fix those mistakes throughout the text, not only the ones they highlighted.

(8) Most supervisors do not mind when their students make honest mistakes. After all, students are scientists in training (or engineering/computer scientists in training, in the case of undergraduate students), and errors are expected along the way. However, virtually all supervisors dislike it when their students repeat the same mistakes due to oversight. Therefore, use your errors in your favor as an opportunity to grow and learn, but try your best not to repeat them.

7.2. Planning and organization

"*Lack of planning on your side should not cause an emergency on my side.*"—Bruno Vilhena Adorno, paraphrasing a frustrated anonymous academic on ~~Twitter~~ X.

One of the main challenges in research is planning and organizing concrete activities, especially at the beginning. By definition, research is uncertain because we might have a good idea about what we want to discover, but we do not know the answer yet. In some cases, even the goal might be highly uncertain! Research at different levels and timeframes will come with distinct uncertainty magnitudes. An undergraduate research project might be entirely sure for the supervisor, but students undertaking it might struggle to visualize the goal. Ph.D. projects tend to be much more uncertain because they must push the boundaries of knowledge. Therefore, most relevant techniques cannot be found in textbooks and are scattered around cutting-edge scientific papers. Sometimes, the required theories do not even exist yet! Sorry, ChatGPT.

To minimize uncertainty and maximize the chances of success, it is crucial to plan and organize the research effectively. Those plans are usually made with one's supervisor or supervisory team and are expected to be followed closely, when possible, or updated and adapted if significant circumstances require it. For example, initial uncertainties might prevent researchers from anticipating major roadblocks in a long-term research project, such as challenges that turn out to be much more complicated than expected. Sometimes, Ph.D. students do not have the necessary background to tackle a major problem in a research problem and cannot acquire it in the limited research timeframe. Still, they might have the intellectual capacity to proceed with the Ph.D. research, tackling alternative problems or using alternative techniques for the same problem they were trying to solve. In any case, it is crucial to stick to agreed-upon plans and corresponding deadlines, and any change should be well justified.

Students and researchers should provide their collaborators, supervisors, and principal investigators plenty of time to work on collaborative research papers and theses. Some universities prescribe the number of days students should expect their supervisors to take to review their theses. Still, the dynamics associated with research papers are sometimes more complicated because supervisors coauthor those papers. Therefore, they might be willing to accept revising more preliminary drafts or might want to revise only the final version of the paper. Others might even participate throughout the whole process in a very interactive way. Hence, students and researchers should always discuss expectations and deadlines with their supervisors and line managers.

7.3. Avoiding pitfalls related to publications

Publications are one of the pillars of academia because they consolidate knowledge from months, perhaps many years of research. Therefore, academics tend to treat them seriously. Due to wrong incentives, such as the "Publish or Perish" motto used in hiring and promotions committees, many people have been engaging in the pernicious practice of maximizing the number of their published papers at the expense of quality. One of the many byproducts of such noxious practice is the perception many people have, notably young researchers, that papers are pieces of paper with little value. Hence, they might engage in questionable practices without fully comprehending the consequences.

To help researchers avoid pitfalls related to publications, here is a list of common things to avoid or be aware of:

(1) If you were planning to submit a paper related to your supervisors' research without their consent, that would constitute serious academic malpractice.
(2) You must abide by your institution's standards and always communicate with your supervisor or line manager about research-related matters, especially publications. Suppose you decided to submit something while affiliated with the university or research institute, even if utterly unrelated to your supervisors' research. If that research undermined the institution's credibility because of errors, academic malpractice, etc., they'd be responsible and have to answer for it.
(3) Complex dynamics exist in any research group, with many different projects and stakeholders involved, funding agencies that must be acknowledged depending on the students involved, and works that might not be disclosed due to contract obligations. Not accounting for those things might cause problems for your supervisors and other academics. Your supervisors or line managers will likely be extremely unhappy if they had to justify themselves to anyone because one of their students or researchers failed to meet their obligations.

7.4. Presentations

Although there are many ways of presenting one's work through a slide presentation, some ways are better than others, so here follows a brief guideline to help in this task:

(1) Slides are meant to support one's presentation and ideas. They are not meant to be standalone such as the paper, report, or thesis that one is presenting. That means slides should summarize what the presenter wants to convey and support what they are orally explaining and describing.
(2) One should not use too many slides. Usually, two minutes per slide is a good rule of thumb. Therefore, a 15-min presentation should have 8 to 10 slides, but definitely no more than 15!
(3) One should use legible diagrams and illustrations to help in visualizing what they are explaining. Slides should not compete with the speaker for the audience's attention. Therefore, it is paramount not to include too many texts. Instead, one should use small sentences that summarize ideas and important points.
(4) A good structure for the slide presentation is the following:
    (a) First slide: Title of the presentation and the authors' names and affiliations.
    (b) Some slides to present the motivation, state-of-the-art, and main challenges.
    (c) One slide to present the main objective, which should be related to the main challenges the presenter has identified in previous slides.
    (d) One slide to present the high-level solution and give the intuition without having to dive deep into the details.
    (e) Some slides to present the relevant details. Not everything needs to be shown, and the presenter should be capable of summarizing their developments in a consistent, concise, and coherent way.
    (f) Some slides presenting the results. Those are meant to support one's claims and provide a critical evaluation of the developed system, framework, or technique.
    (g) A slide summarizing the presentation with the main take-away message.

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