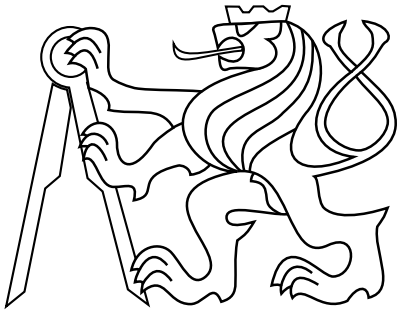
Czech Technical University in Prague

Faculty of Electrical Engineering
Department of Cybernetics
Multi-robot Systems



My Thesis Title
Can Span Multiple Lines

Doctoral Thesis

Ing. John Smith

Prague, January 2021

Ph.D. programme: Electrical Engineering and Information Technology
Branch of study: Artificial Intelligence and Biocybernetics

Supervisor: Ing. My Supervisor, Ph.D.
Supervisor-Specialist: Ing. My Specialist, Ph.D.

Acknowledgments

Firstly, I would like to express my gratitude to my supervisor.

Copyright

Abstract

The study of autonomous Unmanned Aerial Vehicles (UAVs) has become a prominent sub-field of mobile robotics.

Keywords Unmanned Aerial Vehicles, Automatic Control

Abstrakt

Výzkum na poli autonomních bezpilotních prostředků (UAV) se stal významným oborem mobilní robotiky.

Klíčová slova Bezpilotní Prostředky, Automatické Řízení

Abbreviations

GPS Global Positioning System

LiDAR Light Detection and Ranging

UAV Unmanned Aerial Vehicle

Contents

Chapter 1

Introduction

First, introduce the reader to the research topic. Start with the most general view and slowly converge to the particular field, sub-field, and the challenges you face. You can cite others' work here [1c].

1.1 Related works

This section should contain related state-of-the-art works and their relation to the author's work. We usually cite the original works like this [3]. You can also cite multiple papers at once like this [1c], [2a].

1.2 Contributions

This section should describe the author's contributions to the field of research.

1.3 Mathematical notation

It is a good practice to define basic mathematical notation in the introduction. See Table 1.1 for an example.

$\mathbf{x}$, $\boldsymbol{\alpha}$	vector, pseudo-vector, or tuple
$\hat{\mathbf{x}}$, $\hat{\boldsymbol{\omega}}$	unit vector or unit pseudo-vector
$\hat{\mathbf{e}}_1, \hat{\mathbf{e}}_2, \hat{\mathbf{e}}_3$	elements of the *standard basis*
$\mathbf{X}, \boldsymbol{\Omega}$	matrix
$\mathbf{I}$	identity matrix
$x = \mathbf{a}^\intercal \mathbf{b}$	inner product of $\mathbf{a}$, $\mathbf{b} \in \mathbb{R}^3$
$\mathbf{x} = \mathbf{a} \times \mathbf{b}$	cross product of $\mathbf{a}$, $\mathbf{b} \in \mathbb{R}^3$
$\mathbf{x} = \mathbf{a} \circ \mathbf{b}$	element-wise product of $\mathbf{a}$, $\mathbf{b} \in \mathbb{R}^3$
$\mathbf{x}_{(n)} = \mathbf{x}^\intercal \hat{\mathbf{e}}_n$	n^{th} vector element (row), $\mathbf{x}, \mathbf{e} \in \mathbb{R}^3$
$\mathbf{X}_{(a,b)}$	matrix element, (row, column)
x_d	x_d is *desired*, a reference
$\dot{x}, \ddot{x}, \dddot{x}, \ddddot{x}$	1^{st}, 2^{nd}, 3^{rd}, and 4^{th} time derivative of x
$x_{[n]}$	x at the sample n
$\mathbf{A}, \mathbf{B}, \mathbf{x}$	LTI system matrix, input matrix and input vector
SO(3)	3D special orthogonal group of rotations
SE(3)	*SO(3)* $\times \mathbb{R}^3$, special Euclidean group

Table 1.1: Mathematical notation, nomenclature and notable symbols.

Chapter 2

How to write thesis in LaTeX

2.1 Versioning with git

Write the LaTeX in such a way that it could be versioned by git, which will help when collaborating with other people. This means writing **one sentence per line**. Even when you use third-party platforms, such as the OverLeaf, you can still share the repository through Git.

2.2 Mathematical notation with LaTeX

Use bold to visually distinguish vectors and matrices ($\mathbf{x}$, $\mathbf{A}$) and scalars (k, N). Mathematical equations should be numbered and should be part of a sentence. For example, the following equation is a discrete LTI system update

$$\mathbf{x}_{[k+1]} = \mathbf{A}\mathbf{x}_k + \mathbf{B}\mathbf{u}_k, \tag{2.1}$$

where $\mathbf{x}_k \in \mathbb{R}^m$ is the state vector at the sample k, $\mathbf{u}_k \in \mathbb{R}^n$ is the input vector, $\mathbf{A} \in \mathbb{R}^{m \times m}$ is the main system matrix, and $\mathbf{B} \in \mathbb{R}^{m \times n}$ is the system input matrix. Proper punctuation should be used after (2.1), as if it were an ordinary object in the sentence. Do not put any empty lines around the equation. That would create a new paragraph mid-sentence.

2.3 Using footnotes

Do not be afraid to use footnotes for additional information, such as http links[1]. We use footnote links whenever we want to *point* to a website, rather then to cite it as a source. Like with everything, do not overdo it.

2.4 Referencing to document elements

LaTeX allows you to dynamically reference to parts of the documents, such as

- figures: Fig. 2.4, Figure 2.4,
- equations: (2.1),
- code: Lst. 2.1,
- and any other object that can contain `label`.

[1] This repository: `https://github.com/ctu-mrs/thesis_template`.

Check the section in the `document_setup.tex` that contains useful macros for unifying the references:

```
\newcommand{\reffig}[1]{Fig.~\ref{#1}}
\newcommand{\reflst}[1]{Lst.~\ref{#1}}
\newcommand{\refalg}[1]{Alg.~\ref{#1}}
\newcommand{\refsec}[1]{Sec.~\ref{#1}}
\newcommand{\reftab}[1]{Table~\ref{#1}}
\newcommand{\refeq}[1]{\eqref{#1}}
```

Listing 2.1: LaTeX macros for referencing to document elements.

2.5 Abbreviations with Acronym

Abbreviations are handled by the *acronym* package. Example sentence with abbreviations: "UAV is a flying vehicle that commonly uses Light Detection and Ranging (LiDAR) and Global Positioning System (GPS) receiver". Please, read the documentation[2].

2.6 Units of measurements with Siunitx

Typesetting of units has never been more accessible with the Siunitx package. Acceleration is measure in $\mathrm{m\,s^{-2}}$. Gravity accelerates objects at a rate $\approx 9.81\,\mathrm{m\,s^{-2}}$ near the sea level. You can define your units if you want.

2.7 2D Diagrams with Tikz

Tikz is a powerful tool for drawing 2D (and 3D) shapes and diagrams. Check the documentation and examples: `https://www.overleaf.com/learn/latex/TikZ_package`. The benefit of using *Tikz*, instead of some other third-party drawing program, are:

- fonts are the same as in LaTeX,
- you can typeset math in LaTeX,
- you can use references to other parts of your document,
- you can version the image in git,
- the images are easily adjustable while editing your document.

Check Fig. 2.2 for example.

2.8 Data plots with PGFPlots

PGFPlots produces nice 2D and 3D data plots from data stored in CSV. The plot parameters can be versioned and easily adjusted by editing the plot definition file.

- Documentation and manual: `https://ctan.org/pkg/pgfplots`
- Compile the plots individually and then include the pdfs because it can take longer.
- Example located in `fig/plots/example_plot`, see Fig. 2.2.
- You could include the latex file directly. However, it will take longer to compile, and platforms such as Overleaf can have a problem with that.

[2]Acronym package: `http://mirrors.ctan.org/macros/latex/contrib/acronym/acronym.pdf`

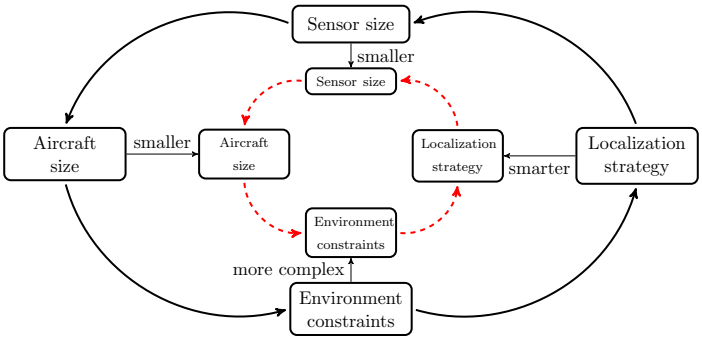


Figure 2.1: Example of a 2D diagram using tikz *PGFPlots*.

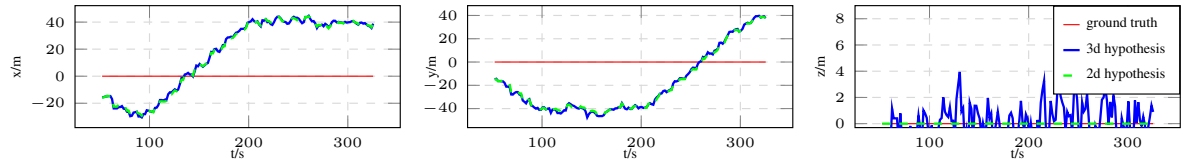


Figure 2.2: Example of a 2D plot using *PGFPlots*.

2.9 3D Plots with Sketch

Sketch is a tool for defining a 3D scene using simple descriptive language. The 3D scene is then converted to *Tikz*, which is later compiled to pdf. The benefits of using *Sketch* are similar to using *Tikz*: LaTeX fonts, versioning using git, and cleanness of the result. See the example image in Fig. 2.3.

- Documentation and manual: `http://www.frontiernet.net/~eugene.ressler/`
- Cross-compilation from *Sketch* to *pdf* using the `fig/sketch/compile_sketch.sh` script.

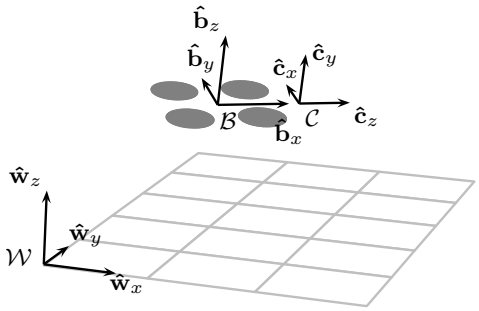


Figure 2.3: Depiction of the used coordinate systems. The image was drawn using *Sketch*.

2.10 Image collages with Subfig

We recommend using the *subfig* packages, which provides the *subfloat* command. It is more versatile than the simpler *subcaption* package. Check the Fig. 2.4 for example.

(a) A UAV, the T650 model.

(b) Another UAV, again, T650 model.

Figure 2.4: The caption should mention both, the Fig. 2.4a and the Fig. 2.4b. You can just refer to them as (a) and (b), but beware, you need to keep it correct as you edit.

2.11 Citations with Biblatex

Biblatex is probably the most powerful citation package for LaTeX. It consumes the standard `.bib` file. However, it can sort and filter the citations using the `keywords` tag. Citing references is done using the `cite` command, e.g., [1c]. You can also define some nice citation boxes, such as this one:

[1c] **T. Baca**, M. Petrlik, M. Vrba, V. Spurny, R. Penicka, D. Hert, *et al.*, "The MRS UAV System: Pushing the Frontiers of Reproducible Research, Real-world Deployment, and Education with Autonomous Unmanned Aerial Vehicles," *Journal of Intelligent & Robotic Systems*, vol. 102, no. 26, pp. 1–28, 1 May 2021

2.12 Image overlays with Tikz

Tikz is very useful to create custom image overlays. The overlay can be set such that the image is spanned by Cartesian coordinates $(x, y) \in [0, 1]^2$ Example can be seen in Fig. 2.5.

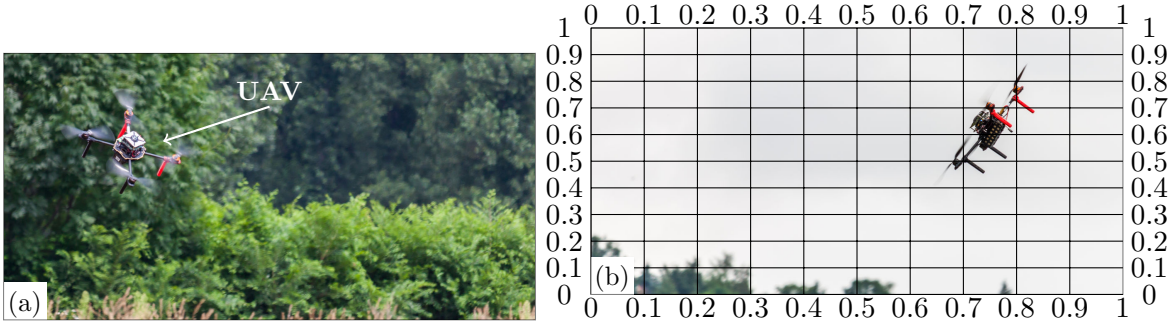


Figure 2.5: Example of using Tikz for image overlays. (a) shows a final product, (b) shows a grid useful for nailing down the coordinates.

Chapter 3

Conclusion

Summarize the achieved results. Can be similar as an abstract or an introduction, however, it should be written in past tense.

Chapter A

References

References to the author's work are listed first, followed by other references cited within this work. The authored references contain his contribution and the number of citations based on Web of Science (WoS), Scopus, and Google Scholar (GS). The citation counts were gathered on insert date here.

A.1 Thesis core publications

Core articles in peer-reviewed journals

[1c] **T. Baca**, M. Petrlik, M. Vrba, V. Spurny, R. Penicka, D. Hert, and M. Saska, "The MRS UAV System: Pushing the Frontiers of Reproducible Research, Real-world Deployment, and Education with Autonomous Unmanned Aerial Vehicles," *Journal of Intelligent & Robotic Systems*, vol. 102, no. 26, pp. 1–28, 1 May 2021, **Contributions: TB: 60%, MP: 10%, VM: 6%, VS: 6%, RP: 6%, DH: 6%, MS: 6%, IF 2.646 (Q2 in Robotics)**.

A.2 Thesis-related author's publications

Thesis-related conference articles

[2a] **T. Baca**, G. Loianno, and M. Saska, "Embedded Model Predictive Control of Unmanned Micro Aerial Vehicles," in *IEEE International Conference on Methods and Models in Automation and Robotics (MMAR)*, IEEE, 2016, pp. 992–997, **80% contribution, citations: 25 in WoS, 29 in Scopus, 88 in GS**.

A.3 Cited references

[3] A. Benallegue, A. Mokhtari, and L. Fridman, "High-order sliding-mode observer for a quadrotor UAV," *International Journal of Robust and Nonlinear Control: IFAC-Affiliated Journal*, vol. 18, no. 4-5, pp. 427–440, 2008.

Chapter B

Appendix B