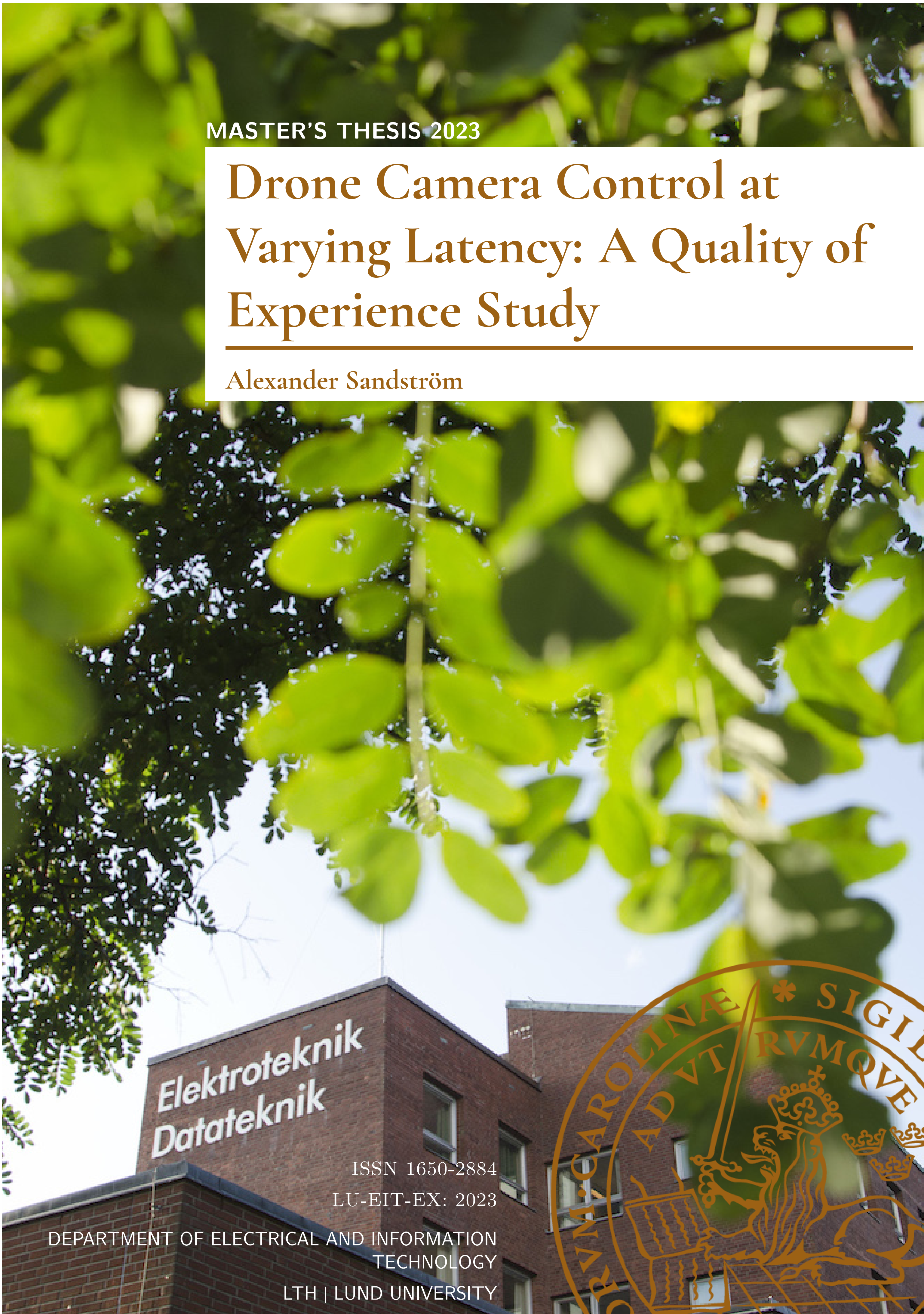
MASTER'S THESIS 2023

Drone Camera Control at Varying Latency: A Quality of Experience Study

Alexander Sandström



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Drone Camera Control at Varying Latency: A Quality of Experience Study

Kamerastyrning på en Drönare vid Varierande Latens: en Studie i Operatörsupplevelse

Alexander Sandström

Drone Camera Control at Varying Latency: A Quality of Experience Study

Alexander Sandström
alexander.h.sandstrom@gmail.com

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Master's thesis work carried out at the Swedish Sea Rescue Society and the Department of Electrical and Information Technology, Lund University.

Supervisors: Fredrik Falkman, fredrik.falkman@ssrs.se
William Tärneberg, william.tarneberg@eit.lth.se

Examiner: Maria Kihl, maria.kihl@eit.lth.se

Abstract

Your abstract should capture, in English, the whole thesis with focus on the problem and solution in 150 words. It should be placed on a separate right-hand page, with an additional *1cm* margin on both left and right. Avoid acronyms, footnotes, and references in the abstract if possible.

Leave a *2cm* vertical space after the abstract and provide a few keywords relevant for your report. Use five to six words, of which at most two should be from the title.

Keywords: MSc, BSc, template, report, style, structure

Acknowledgements

If you want to thank people, do it here, on a separate right-hand page. Both the U.S. *acknowledgments* and the British *acknowledgements* spellings are acceptable.

Contents

Chapter 1
Introduction

This thesis aims to compare a few different ways in which a camera onboard a drone can be controlled in real-time and evaluate the operator's experience with the different controls at different latencies. The different controls are to be evaluated through a Quality of Experience (QoE) user experiment, where subjective measurements will be collected from experienced and inexperienced drone operators performing a task with the different controls.

Chapter 2
Background

This thesis work is a collaboration between the Swedish Sea Rescue Society and the Department of Electrical and Information Technology at (+the Faculty of Engineering?) Lund University.

2.1 Motivation

With the promise of real-time remote control over 5G, the systems of tomorrow will be heavily reliant on the uptime and latency of the network, making these systems exposed to vulnerabilities should the network experience high contingency or failure. Therefore, Having a system that can operate in a degraded state, i.e. with high latency, is a necessity. Furthermore, when 5G is more widely adopted and stable, Internet Service Providers might offer plans with different latencies, giving the user a choice of how much they want to pay for latency that their particular application needs.

In the emerging field of research around drones and remote control there is a clear correlation between latency and the operator's experience. However, a comparison of different types of controls and their effect on the operator at different latencies is, as far as the student's knowledge goes, not documented in the current body of research.

The technical challenges that SSRS face align very well with the challenges that are posed in general so-called "Industry 4.0"-applications, and the harsh conditions under which the drone operates—flying above the sea—makes a strong argument for applying the learning outcomes from previous QoE research.

Furthermore, SSRS does not have an estimate of the latency of the video feed from the drone, making it difficult to determine how the camera should be controlled, be it by swiping, pressing they arrow-keys or setting a location on a map for it to look at. In the emerging field of research around drones and remote control, there is a clear correlation between latency and the operator's experience. However, a comparison of different types of controls and their effect on the operator at different latencies are, as far as the student's knowledge goes, not documented in the current body of research.

This is a reference to [4].

2.2 Swedish Sea Rescue Society

As can be read on their website [2], the Swedish Sea Rescue Society (SSRS) is a non-profit organization that was founded at a conference in Stockholm in 1906 due to Sweden receiving criticism of its' poor sea rescue. Today, it is a foundation with 40 employees and over 143 000 members, and with their 2400 volunteers manning their different rescue vessels, they carry out around 90% of all sea rescues in Sweden all year around.

2.2.1 Innovation

As stated in their statutes [3], the mission of SSRS is not solely to carry out these rescue missions but to also innovate and collaborate in the area of maritime rescue as well as other aiding activities in society as a whole. As a result of this, the drone project that this thesis is a part of has been conceived along with other innovation projects such as foiling rescue boats or improved rescue vehicles [1].

2.2.2 Drone Project

Currently, SSRS has a drone connected to the mobile network that can fly towards and loiter around a set of waypoints given on a map, while also providing video from the gimbal-mounted camera. The drone flies with a hardware module running the autopilot software ArduPilot which also supports camera gimbal control. The mechanical gimbal assembly supports three degrees of freedom, however, the software necessary for remotely controlling the camera gimbal is not implemented.

2.3 Quality of Experience

2.4 Previous Work

Chapter 3
Method

3.1 Hardware

3.2 Experimental Setup

3.3 Experimental Procedure

Chapter 4

Results

Chapter 5
Discussion

Chapter 6

Conclusion

Chapter 7

Future Work

References

[1] Surtsey innovation projects. http://www.surtsey.org/. Accessed: 2023-02-03.

[2] Swedish sea rescue society, information in english. https://www.sjoraddning.se/information-english. Accessed: 2023-02-01.

[3] Swedish sea rescue society, statues. https://www.sjoraddning.se/sites/default/files/stadgar_ssrs_antagna_2018.pdf. Accessed: 2023-02-03.

[4] William Tärneberg, Omar Hamsis, John Hedlund, Kjell Brunnström, Emma Fitzgerald, Andreas Johnsson, Viktor Berggren, Maria Kihl, Akhila Rao, Rebecca Steinert, and Caner Kilinc. Towards intelligent industry 4.0 5g networks: A first throughput and qoe measurement campaign, 2020.

Appendices

Appendix A
About This Document

The following environments and tools were used to create this document:

- operating system: Mac OS X 10.14
- tex distribution: MacTeX-2014, `http://www.tug.org/mactex/`
- tex editor: Texmaker 5.0.2 for Mac, `http://www.xm1math.net/texmaker/` for its XeLaTeX flow (recommended) or pdfLaTeX flow
- bibtex editor: BibDesk 1.6.3 for Mac, `http://bibdesk.sourceforge.net/`
- fonts `cslthse-msc.cls` document class):

  for XeLaTeX: TeX Gyre Termes, TeX Gyre Heros, `TeX Gyre Cursor` (installed from the TeXLive 2013)

  for pdfLaTeX: TeX Gyre font packages: tgtermes.sty, tgheros.sty, tgcursor.sty, gtx-math.sty (available through TeXLive 2013)
- picture editor: OmniGraffle Professional 5.4.2

A list of the essential LaTeXpackages needed to compile this document follows (all except `hyperref` are included in the document class):

- `fontspec`, to access local fonts, needs the XeLaTeX flow
- `geometry`, for page layout
- `titling`, for formatting the title page
- `fancyhdr`, for custom headers and footers
- `abstract`, for customizing the abstract

- `titlesec`, for custom chapters, sections, etc.
- `caption`, for custom tables and figure captions
- `hyperref`, for producing PDF with hyperlinks
- `appendix`, for appendices
- `printlen`, for printing text sizes
- `textcomp`, for text companion fonts (e.g. bullet)
- `pdfpages`, to include the popular science summary page at the end

Other useful packages:

- `listings`, for producing code listings with syntax colouring and line numbers

A.1 Page Size and Margins

Use A4 paper, with the text margins given in Table A.1.

Table A.1: Text margins for A4.

margin	space
top	3.0cm
bottom	3.0cm
left (inside)	2.5cm
right (outside)	2.5cm
binding offset	1.0cm

A.2 Typeface and Font Sizes

The fonts to use for the reports are **TeX Gyre Termes** (a **Times New Roman** clone) for serif fonts, **TeX Gyre Heros** (a **Helvetica** clone) for sans-serif fonts, and finally **`TeX Gyre Cursor`** (a **`Courier`** clone) as mono-space font. All these fonts are included with the TeXLive 2013 installation. Table A.2 lists the most important text elements and the associated fonts.

A.2.1 Headers and Footers

Note that the page headers are aligned towards the outside of the page (right on the right-hand page, left on the left-hand page) and they contain the section title on the right and the chapter title on the left respectively, in SmallCaps. The footers contain only page numbers on the exterior of the page, aligned right or left depending on the page. The lines used to delimit the headers and footers from the rest of the page are $0.4pt$ thick, and are as long as the text.

Table A.2: Font types, faces and sizes to be used.

Element	Face	Size	LaTeXsize
Ch. label	serif, bold	24.88pt	\huge
Chapter	serif, bold	24.88pt	\Huge
Section	sans-serif, bold	20.74pt	\LARGE
Subsection	sans-serif, bold	17.28pt	\Large
Subsubsection	sans-serif, bold	14.4pt	\large
Body	serif	12pt	\normalsize
Header	serif, SmallCaps	10pt	
Footer (page numbers)	serif, regular	12pt	
Figure label	**serif, bold**	12pt	
Figure caption	serif, regular	12pt	
In figure	sans-serif	*any*	
Table label	**serif, bold**	12pt	
Table caption and text	serif, regular	12pt	
`Listings`	`mono-space`	$\leq$ 12pt	

A.2.2 Chapters, Sections, Paragraphs

Chapter, section, subsection, etc. names are all left aligned, and numbered as in this document.

Chapters always start on the right-hand page, with the label and title separated from the rest of the text by a $0.4pt$ thick line.

Paragraphs are justified (left and right), using single line spacing. Note that the first paragraph of a chapter, section, etc. is not indented, while the following are indented.

A.2.3 Tables

Table captions should be located above the table, justified, and spaced 2.0cm from left and right (important for very long captions). Tables should be numbered, but the numbering is up to you, and could be, for instance:

- **Table X.Y** where X is the chapter number and Y is the table number within that chapter. (This is the default in LaTeX. More on LaTeX can be found on-line, including whole books, such as [**?**].) or

- **Table Y** where Y is the table number within the whole report

As a recommendation, use regular paragraph text in the tables, bold headings and avoid vertical lines (see Table A.2).

A.2.4 Figures

Figure labels, numbering, and captions should be formed similarly to tables. As a recommendation, use vector graphics in figures (Figure A.1), rather than bitmaps (Figure A.2). Text within figures usually looks better with sans-serif fonts.

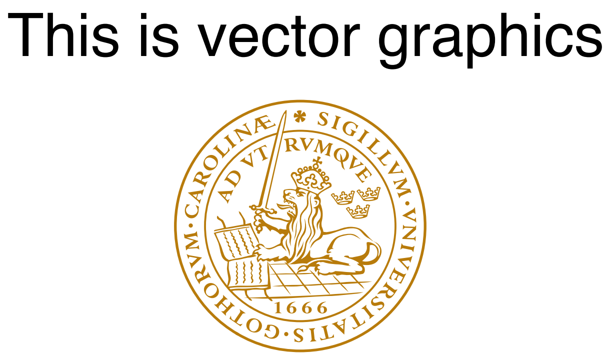


Figure A.1: A PDF vector graphics figure. Notice the numbering and placement of the caption. The caption text is indented 2.0cm from both left and right text margin.

Figure A.2: A JPEG bitmap figure. Notice the bad quality of such an image when scaling it. Sometimes bitmap images are unavoidable, such as for screen dumps.

For those interested in delving deeper into the design of graphical information display, please refer to books such as [**?**, **?**].

A.3 Mathematical Formulae and Equations

You are free to use in-text equations and formulae, usually in *italic serif* font. For instance: $S = \sum_i a_i$. We recommend using numbered equations when you do need to refer to the specific equations:

$$E = \int_0^\delta P(t)dt \quad \longleftrightarrow \quad E = mc^2 \tag{A.1}$$

The numbering system for equations should be similar to that used for tables and figures.

A.4 References

Your references should be gathered in a **References** section, located at the end of the document (before **Appendices**). We recommend using number style references, ordered as appearing in the document or alphabetically. Have a look at the references in this template in order to figure out the style, fonts and fields. Web references are acceptable (with restraint) as long as you specify the date you accessed the given link [?, ?]. You may of course use URLs directly in the document, using mono-space font, i.e. `http://cs.lth.se/`.

Make sure you add references as close to the claim as possible [?], as shown, not at the end of a whole paragraph. Notice also that there is a space before the reference; best is to use `~\cite{ref}`, to allow for unbreakable spaces. References should not be used after the period marking the end of sentence. Using the reference as follows (end of paragrah, after period) is *strongly discouraged*, since it says nothing about which specific claim you provide the reference for. [?]

A.5 Colours

As a general rule, all theses are printed in black-and-white, with the exception of selected parts in selected theses that need to display colour images essential to describing the thesis outcome (*computer graphics*, for instance).

A strong requirement is for using **black text on white background** in your document's main text. Otherwise we do encourage using colours in your figures, or other elements (i.e. the colour marking internal and external references) that would make the document more readable on screen. You may also emphasize table rows, columns, cells, or headers using white text on black background, or black text on light grey background.

Note that the document should look good in black-and-white print. Colours are often rendered using monochrome textures in print, which makes them look different from on screen versions. This means that you should choose your colours wisely, and even opt for black-and-white textures when the distinction between colours is hard to make in print. The best way to check how your document looks, is to print out a copy yourself.

The LaTeX class defines also a few *LTH* standard colours, which you could use in your document for various elements, to adhere to the standard university profile.
These are: LTHblue, LTHbronze, LTHgreen, LTHpink, LTHcyan, LTHgrey.

Appendix B

Language

You are strongly encouraged to write your report in English, for two reasons. First, it will improve your use of English language. Second, it will increase visibility for you, the author, as well as for the Department of Computer Science, and for your host company (if any).

However, note that your examiner (and supervisors) are not there to provide you with extensive language feedback. We recommend that you check the language used in your report in several ways:

Reference books dedicated to language issues can be very useful. [?]

Spelling and grammar checkers which are usually available in the commonly used text editing environments.

Colleagues and friends willing to provide feedback your writing.

Studieverkstaden is a university level workshop, that can help you with language related problems (see Studieverkstaden's web page).

Websites useful for detecting language errors or strange expressions, such as

- `http://translate.google.com`
- `http://www.gingersoftware.com/grammarcheck/`

B.1 Style Elements

Next, we will just give some rough guidelines for good style in a report written in English. Your supervisor and examiner as well as the aforementioned **Studieverkstad** might have a different take on these, so we recommend you follow their advice whenever in doubt. If you want a reference to a short style guide, have a look at [?].

Widows and Orphans

Avoid *widows* and *orphans*, namely words or short lines at the beginning or end of a paragraph, which are left dangling at the top or bottom of a column, separated from the rest of the paragraph.

Footnotes

We strongly recommend you avoid footnotes. To quote from [?], *Footnotes are frequently misused by containing information which should either be placed in the text or excluded altogether. They should be avoided as a general rule and are acceptable only in exceptional cases when incorporation of their content in the text [is] not possible.*

Active vs. Passive Voice

Generally active voice (*I ate this apple.*) is easier to understand than passive voice (*This apple has been eaten (by me).*) In passive voice sentences the actor carrying out the action is often forgotten, which makes the reader wonder who actually performed the action. In a report is important to be clear about who carried out the work. Therefore we recommend to use active voice, and preferably the plural form *we* instead of *I* (even in single author reports).

Long and Short Sentences

A nice brief list of sentence problems and solutions is given in [?]. Using choppy sentences (too short) is a common problem of many students. The opposite, using too long sentences, occurs less often, in our experience.

Subject-Predicate Agreement

A common problem of native Swedish speakers is getting the subject-predicate (verb) agreement right in sentences. Note that a verb must agree in person and number with its subject. As a rough tip, if you have subject ending in *s* (plural), the predicate should not, and the other way around. Hence, *only one s*. Examples follow:

incorrect He have to take this road.

correct He has to take this road.

incorrect These words forms a sentence.

correct These words form a sentence.

In more complex sentences, getting the agreement right is trickier. A brief guide is given in the *20 Rules of Subject Verb Agreement* [?].

Appendix C
Structure

It is a good idea to discuss the structure of the report with your supervisor rather early in your writing. Given next is a generic structure that is a starting point, but by no means the absolute standard. Your supervisor should provide a better structure for the specific field you are writing your thesis in. Note also that the naming of the chapters is not compulsory, but may be a helpful guideline.

Introduction should give the background of your work. Important parts to cover:

- Give the context of your work, have a short introduction to the area.
- Define the problem you are solving (or trying to solve).
- Specify your contributions. What does this particular work/report bring to the research are or to the body of knowledge? How is the work divided between the co-authors? (This part is essential to pinpoint individual work. For theses with two authors, it is compulsory to identify which author has contributed with which part, both with respect to the work and the report.)
- Describe related work (literature study). Besides listing other work in the area, mention how is it related or relevant to your work. The tradition in some research area is to place this part at the end of the report (check with your supervisor).

Approach should contain a description of your solution(s), with all the theoretical background needed. On occasion this is replaced by a subset or all of the following:

- **Method**: describe how you go about solving the problem you defined. Also how do you show/prove that your solution actually works, and how well does it work.
- **Theory**: should contain the theoretical background needed to understand your work, if necessary.
- **Implementation**: if your work involved building an artefact/implementation, give the details here. Note, that this should not, as a rule, be a chronological

description of your efforts, but a view of the result. There is a place for insights and lamentation later on in the report, in the Discussion section.

Evaluation is the part where you present the finds. Depending on the area this part contains a subset or all of the following:

- **Experimental Setup** should describe the details of the method used to evaluate your solution(s)/approach. Sometimes this is already addressed in the **Method**, sometimes this part replaces **Method**.
- **Results** contains the data (as tables, graphs) obtained via experiments (benchmarking, polls, interviews). Here you should also describe the individual tables or graphs in text, pointing out interesting outliers and trends.
- **Discussion** allows for a longer discussion and interpretation of the results from the evaluation, including extrapolations and/or expected impact. Focus here on a broader view of the results, talking about the relation between the different finds.[1] This might also be a good place to describe your positive and negative experiences related to the work you carried out.

Occasionally these sections are intermingled, if this allows for a better presentation of your work. However, try to distinguish between measurements or hard data (results) and extrapolations, interpretations, or speculations (discussion).

Conclusions should summarize your findings and possible improvements or recommendations.

Bibliography is a must in a scientific report. LaTeX and `bibtex` offer great support for handling references and automatically generating bibliographies.

Appendices should contain lengthy details of the experimental setup, mathematical proofs, code download information, and shorter code snippets. Avoid longer code listings. Source code should rather be made available for download on a website or on-line repository of your choosing.

[1]Bad practice is to display graphs in Results and then describe them textually one by one in here. No! Both sections should have some discussion, but one targets individual finds and the other tries to bridge between these adopting a more overarching viewpoint.

EXAMENSARBETE Application Specific Instruction-set Processor Using a Parametrizable multi-SIMD Synthesizeable Model Supporting Design Space Exploration
STUDENT Magnus Hultin
HANDLEDARE Flavius Gruian (LTH)
EXAMINATOR Krzysztof Kuchcinski (LTH)

Parametrisk processor modell för design utforskning

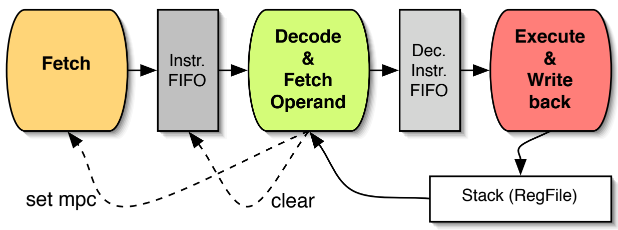
POPULÄRVETENSKAPLIG SAMMANFATTNING **Magnus Hultin**

Applikations-specifika processorer är allt mer vanligt för få ut rätt prestanda med så lite resurser som möjligt. Detta arbete har en parametrisk modell för att kunna testa hur mycket resurser som behövs för en specifik applikation.

För att öka prestandan i dagens processorer finns det vektorenheter och flera kärnor i processorer. Vektorenheten finns till för att kunna utföra en operation på en mängd data samtidigt och flera kärnor gör att man kan utföra fler instruktioner samtidigt. Ofta är processorerna designade för att kunna stödja en mängd olika datorprogram. Detta resulterar i att det blir kompromisser som kan påverka prestandan för vissa program och vara överflödigt för andra. I t.ex. videokameror, mobiltelefoner, medicinsk utrustning, digital kameror och annan inbyggd elektronik, kan man istället använda en processor som saknar vissa funktioner men som istället är mer energieffektiv. Man kan jämföra det med att frakta ett paket med en stor lastbil istället för att använda en mindre bil där samma paketet också skulle få plats.

I mitt examensarbete har jag skrivit en modell som kan användas för att snabbt designa en processor enligt vissa parametrar. Dessa parametrar väljs utifrån vilket eller vilka program man tänkta köra på den. Vissa program kan t.ex. lättare använda flera kärnor och vissa program kan använda korta eller längre vektorenheter för dess data.

Modellen testades med olika multimedia program. Den mest beräkningsintensiva och mest upprepande delen av programmen användes. Dessa kallas för kärnor av programmen. Kärnorna som användes var ifrån MPEG och JPEG, som används för bildkomprimering och videokomprimering.



Resultatet visar att det finns en prestanda vinst jämfört med generella processorer men att detta också ökar resurserna som behövs. Detta trots att den generella processorn har nästan dubbelt så hög klockfrekvens än dem applikationsspecifika processorerna. Resultatet visar också att schemaläggning av instruktionerna i programmen spelar en stor roll för att kunna utnyttja resurserna som finns tillgängliga och därmed öka prestandan. Med den schemaläggningen som utnyttjade resurserna bäst var prestandan minst 79% bättre än den generella processorn.