UNIVERSITY NAME

DOCTORAL THESIS

Thesis Title

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A thesis submitted in fulfillment of the requirements
for the degree of Doctor of Philosophy

in the

Research Group Name
Department or School Name

September 16, 2019

Declaration of Authorship

I, John SMITH, declare that this thesis titled, "Thesis Title" and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed:

Date:

"Thanks to my solid academic training, today I can write hundreds of words on virtually any topic without possessing a shred of information, which is how I got a good job in journalism."

Dave Barry

UNIVERSITY NAME

Abstract

Faculty Name
Department or School Name

Doctor of Philosophy

Thesis Title

by John SMITH

The Thesis Abstract is written here (and usually kept to just this page). The page is kept centered vertically so can expand into the blank space above the title too…

Acknowledgements

The acknowledgments and the people to thank go here, don’t forget to include your project advisor…

Contents

List of Figures

List of Tables

List of Abbreviations

WSF	**W**hat (it) **S**tands **F**or
UAV	**U**nmanned **A**erial **V**ehicle

Aircraft without human pilot onboard

Physical Constants

Speed of Light $c_0 = 2.997\,924\,58 \times 10^8\,\mathrm{m\,s^{-1}}$ (exact)

List of Symbols

a	distance	m
P	power	W ($J\,s^{-1}$)
ω	angular frequency	rad

For/Dedicated to/To my…

Chapter 1

Chapter Title Here

1.1 Welcome and Thank You

Welcome to this LaTeX Thesis Template, a beautiful and easy to use template for writing a thesis using the LaTeX typesetting system.

If you are writing a thesis (or will be in the future) and its subject is technical or mathematical (though it doesn't have to be), then creating it in LaTeX is highly recommended as a way to make sure you can just get down to the essential writing without having to worry over formatting or wasting time arguing with your word processor.

LaTeX is easily able to professionally typeset documents that run to hundreds or thousands of pages long. With simple mark-up commands, it automatically sets out the table of contents, margins, page headers and footers and keeps the formatting consistent and beautiful. One of its main strengths is the way it can easily typeset mathematics, even *heavy* mathematics. Even if those equations are the most horribly twisted and most difficult mathematical problems that can only be solved on a super-computer, you can at least count on LaTeX to make them look stunning.

1.2 Learning LaTeX

LaTeX is not a WYSIWYG (What You See is What You Get) program, unlike word processors such as Microsoft Word or Apple's Pages. Instead, a document written for LaTeX is actually a simple, plain text file that contains *no formatting*. You tell LaTeX how you want the formatting in the finished document by writing in simple commands amongst the text, for example, if I want to use *italic text for emphasis*, I write the `\emph{text}` command and put the text I want in italics in between the curly braces. This means that LaTeX is a "mark-up" language, very much like HTML.

1.2.1 A (not so short) Introduction to LaTeX

If you are new to LaTeX, there is a very good eBook – freely available online as a PDF file – called, "The Not So Short Introduction to LaTeX". The book's title is typically shortened to just *lshort*. You can download the latest version (as it is occasionally updated) from here: `http://www.ctan.org/tex-archive/info/lshort/english/lshort.pdf`

It is also available in several other languages. Find yours from the list on this page: `http://www.ctan.org/tex-archive/info/lshort/`

It is recommended to take a little time out to learn how to use LaTeX by creating several, small 'test' documents, or having a close look at several templates on:
`http://www.LaTeXTemplates.com`

Making the effort now means you're not stuck learning the system when what you *really* need to be doing is writing your thesis.

1.2.2 A Short Math Guide for LaTeX

If you are writing a technical or mathematical thesis, then you may want to read the document by the AMS (American Mathematical Society) called, "A Short Math Guide for LaTeX". It can be found online here: `http://www.ams.org/tex/amslatex.html` under the "Additional Documentation" section towards the bottom of the page.

1.2.3 Common LaTeX Math Symbols

There are a multitude of mathematical symbols available for LaTeX and it would take a great effort to learn the commands for them all. The most common ones you are likely to use are shown on this page: `http://www.sunilpatel.co.uk/latex-type/latex-math-symbols/`

You can use this page as a reference or crib sheet, the symbols are rendered as large, high quality images so you can quickly find the LaTeX command for the symbol you need.

1.2.4 LaTeX on a Mac

The LaTeX distribution is available for many systems including Windows, Linux and Mac OS X. The package for OS X is called MacTeX and it contains all the applications you need – bundled together and pre-customized – for a fully working LaTeX environment and work flow.

MacTeX includes a custom dedicated LaTeX editor called TeXShop for writing your '`.tex`' files and BibDesk: a program to manage your references and create your bibliography section just as easily as managing songs and creating playlists in iTunes.

1.3 Getting Started with this Template

If you are familiar with LaTeX, then you should explore the directory structure of the template and then proceed to place your own information into the *THESIS INFORMATION* block of the `main.tex` file. You can then modify the rest of this file to your unique specifications based on your degree/university. Section 1.5 on page 4 will help you do this. Make sure you also read section 1.7 about thesis conventions to get the most out of this template.

If you are new to LaTeX it is recommended that you carry on reading through the rest of the information in this document.

Before you begin using this template you should ensure that its style complies with the thesis style guidelines imposed by your institution. In most cases this template style and layout will be suitable. If it is not, it may only require a small change to bring the template in line with your institution's recommendations. These modifications will need to be done on the `MastersDoctoralThesis.cls` file.

1.3.1 About this Template

This LaTeX Thesis Template is originally based and created around a LaTeX style file created by Steve R. Gunn from the University of Southampton (UK), department of Electronics and Computer Science. You can find his original thesis style file at his site, here: http://www.ecs.soton.ac.uk/~srg/softwaretools/document/templates/

Steve's ecsthesis.cls was then taken by Sunil Patel who modified it by creating a skeleton framework and folder structure to place the thesis files in. The resulting template can be found on Sunil's site here: http://www.sunilpatel.co.uk/thesis-template

Sunil's template was made available through http://www.LaTeXTemplates.com where it was modified many times based on user requests and questions. Version 2.0 and onwards of this template represents a major modification to Sunil's template and is, in fact, hardly recognisable. The work to make version 2.0 possible was carried out by Vel and Johannes Böttcher.

1.4 What this Template Includes

1.4.1 Folders

This template comes as a single zip file that expands out to several files and folders. The folder names are mostly self-explanatory:

Appendices – this is the folder where you put the appendices. Each appendix should go into its own separate `.tex` file. An example and template are included in the directory.

Chapters – this is the folder where you put the thesis chapters. A thesis usually has about six chapters, though there is no hard rule on this. Each chapter should go in its own separate `.tex` file and they can be split as:

- Chapter 1: Introduction to the thesis topic
- Chapter 2: Background information and theory
- Chapter 3: (Laboratory) experimental setup
- Chapter 4: Details of experiment 1
- Chapter 5: Details of experiment 2
- Chapter 6: Discussion of the experimental results
- Chapter 7: Conclusion and future directions

This chapter layout is specialised for the experimental sciences, your discipline may be different.

Figures – this folder contains all figures for the thesis. These are the final images that will go into the thesis document.

1.4.2 Files

Included are also several files, most of them are plain text and you can see their contents in a text editor. After initial compilation, you will see that more auxiliary files are created by LaTeX or BibTeX and which you don't need to delete or worry about:

example.bib – this is an important file that contains all the bibliographic information and references that you will be citing in the thesis for use with BibTeX. You can write it manually, but there are reference manager programs available that will create and manage it for you. Bibliographies in LaTeX are a large subject and you may need to read about BibTeX before starting with this. Many modern reference managers will allow you to export your references in BibTeX format which greatly eases the amount of work you have to do.

MastersDoctoralThesis.cls – this is an important file. It is the class file that tells LaTeX how to format the thesis.

main.pdf – this is your beautifully typeset thesis (in the PDF file format) created by LaTeX. It is supplied in the PDF with the template and after you compile the template you should get an identical version.

main.tex – this is an important file. This is the file that you tell LaTeX to compile to produce your thesis as a PDF file. It contains the framework and constructs that tell LaTeX how to layout the thesis. It is heavily commented so you can read exactly what each line of code does and why it is there. After you put your own information into the *THESIS INFORMATION* block – you have now started your thesis!

Files that are *not* included, but are created by LaTeX as auxiliary files include:

main.aux – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main `.tex` file.

main.bbl – this is an auxiliary file generated by BibTeX, if it is deleted, BibTeX simply regenerates it when you run the `main.aux` file. Whereas the `.bib` file contains all the references you have, this `.bbl` file contains the references you have actually cited in the thesis and is used to build the bibliography section of the thesis.

main.blg – this is an auxiliary file generated by BibTeX, if it is deleted BibTeX simply regenerates it when you run the main `.aux` file.

main.lof – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main `.tex` file. It tells LaTeX how to build the *List of Figures* section.

main.log – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main `.tex` file. It contains messages from LaTeX, if you receive errors and warnings from LaTeX, they will be in this `.log` file.

main.lot – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main `.tex` file. It tells LaTeX how to build the *List of Tables* section.

main.out – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main `.tex` file.

So from this long list, only the files with the `.bib`, `.cls` and `.tex` extensions are the most important ones. The other auxiliary files can be ignored or deleted as LaTeX and BibTeX will regenerate them.

1.5 Filling in Your Information in the `main.tex` File

You will need to personalise the thesis template and make it your own by filling in your own information. This is done by editing the `main.tex` file in a text editor or your favourite LaTeX environment.

Open the file and scroll down to the third large block titled *THESIS INFORMATION* where you can see the entries for *University Name*, *Department Name*, etc ...

Fill out the information about yourself, your group and institution. You can also insert web links, if you do, make sure you use the full URL, including the `http://` for this. If you don't want these to be linked, simply remove the `\href{url}{name}` and only leave the name.

When you have done this, save the file and recompile `main.tex`. All the information you filled in should now be in the PDF, complete with web links. You can now begin your thesis proper!

1.6 The `main.tex` File Explained

The `main.tex` file contains the structure of the thesis. There are plenty of written comments that explain what pages, sections and formatting the LaTeX code is creating. Each major document element is divided into commented blocks with titles in all capitals to make it obvious what the following bit of code is doing. Initially there seems to be a lot of LaTeX code, but this is all formatting, and it has all been taken care of so you don't have to do it.

Begin by checking that your information on the title page is correct. For the thesis declaration, your institution may insist on something different than the text given. If this is the case, just replace what you see with what is required in the *DECLARATION PAGE* block.

Then comes a page which contains a funny quote. You can put your own, or quote your favourite scientist, author, person, and so on. Make sure to put the name of the person who you took the quote from.

Following this is the abstract page which summarises your work in a condensed way and can almost be used as a standalone document to describe what you have done. The text you write will cause the heading to move up so don't worry about running out of space.

Next come the acknowledgements. On this page, write about all the people who you wish to thank (not forgetting parents, partners and your advisor/supervisor).

The contents pages, list of figures and tables are all taken care of for you and do not need to be manually created or edited. The next set of pages are more likely to be optional and can be deleted since they are for a more technical thesis: insert a list of abbreviations you have used in the thesis, then a list of the physical constants and numbers you refer to and finally, a list of mathematical symbols used in any formulae. Making the effort to fill these tables means the reader has a one-stop place to refer to instead of searching the internet and references to try and find out what you meant by certain abbreviations or symbols.

The list of symbols is split into the Roman and Greek alphabets. Whereas the abbreviations and symbols ought to be listed in alphabetical order (and this is *not* done automatically for you) the list of physical constants should be grouped into similar themes.

The next page contains a one line dedication. Who will you dedicate your thesis to?

Finally, there is the block where the chapters are included. Uncomment the lines (delete the `%` character) as you write the chapters. Each chapter should be written in its own file and put into the *Chapters* folder and named `Chapter1`, `Chapter2`, etc...Similarly for the appendices, uncomment the lines as you need them. Each appendix should go into its own file and placed in the *Appendices* folder.

After the preamble, chapters and appendices finally comes the bibliography. The bibliography style (called *`authoryear`*) is used for the bibliography and is a fully featured style that will even include links to where the referenced paper can be found online. Do not underestimate how grateful your reader will be to find that a reference to a paper is just a click away. Of course, this relies on you putting the URL information into the BibTeX file in the first place.

1.7 Thesis Features and Conventions

To get the best out of this template, there are a few conventions that you may want to follow.

One of the most important (and most difficult) things to keep track of in such a long document as a thesis is consistency. Using certain conventions and ways of doing things (such as using a Todo list) makes the job easier. Of course, all of these are optional and you can adopt your own method.

1.7.1 Printing Format

This thesis template is designed for double sided printing (i.e. content on the front and back of pages) as most theses are printed and bound this way. Switching to one sided printing is as simple as uncommenting the *oneside* option of the `documentclass` command at the top of the `main.tex` file. You may then wish to adjust the margins to suit specifications from your institution.

The headers for the pages contain the page number on the outer side (so it is easy to flick through to the page you want) and the chapter name on the inner side.

The text is set to 11 point by default with single line spacing, again, you can tune the text size and spacing should you want or need to using the options at the very start of `main.tex`. The spacing can be changed similarly by replacing the *singlespacing* with *onehalfspacing* or *doublespacing*.

1.7.2 Using US Letter Paper

The paper size used in the template is A4, which is the standard size in Europe. If you are using this thesis template elsewhere and particularly in the United States, then you may have to change the A4 paper size to the US Letter size. This can be done in the margins settings section in `main.tex`.

Due to the differences in the paper size, the resulting margins may be different to what you like or require (as it is common for institutions to dictate certain margin sizes). If this is the case, then the margin sizes can be tweaked by modifying the values in the same block as where you set the paper size. Now your document should be set up for US Letter paper size with suitable margins.

1.7.3 References

The `biblatex` package is used to format the bibliography and inserts references such as this one (Hawthorn, Weber, and Scholten, 2001). The options used in the `main.tex` file mean that the in-text citations of references are formatted with the author(s) listed with the date of the publication. Multiple references are separated by semicolons (e.g. (Wieman and Hollberg, 1991; Hawthorn, Weber, and Scholten, 2001)) and references with more than three authors only show the first author with *et al.* indicating there are more authors (e.g. (Arnold et al., 1998)). This is done automatically for you. To see how you use references, have a look at the `Chapter1.tex` source file. Many reference managers allow you to simply drag the reference into the document as you type.

Scientific references should come *before* the punctuation mark if there is one (such as a comma or period). The same goes for footnotes[1]. You can change this but the most important thing is to keep the convention consistent throughout the thesis.

[1] Such as this footnote, here down at the bottom of the page.

Footnotes themselves should be full, descriptive sentences (beginning with a capital letter and ending with a full stop). The APA6 states: “Footnote numbers should be superscripted, [...], following any punctuation mark except a dash.” The Chicago manual of style states: “A note number should be placed at the end of a sentence or clause. The number follows any punctuation mark except the dash, which it precedes. It follows a closing parenthesis.”

The bibliography is typeset with references listed in alphabetical order by the first author’s last name. This is similar to the APA referencing style. To see how LaTeX typesets the bibliography, have a look at the very end of this document (or just click on the reference number links in in-text citations).

A Note on bibtex

The bibtex backend used in the template by default does not correctly handle unicode character encoding (i.e. "international" characters). You may see a warning about this in the compilation log and, if your references contain unicode characters, they may not show up correctly or at all. The solution to this is to use the biber backend instead of the outdated bibtex backend. This is done by finding this in `main.tex`: *`backend=bibtex`* and changing it to *`backend=biber`*. You will then need to delete all auxiliary BibTeX files and navigate to the template directory in your terminal (command prompt). Once there, simply type `biber main` and biber will compile your bibliography. You can then compile `main.tex` as normal and your bibliography will be updated. An alternative is to set up your LaTeX editor to compile with biber instead of bibtex, see here for how to do this for various editors.

1.7.4 Tables

Tables are an important way of displaying your results, below is an example table which was generated with this code:

```
\begin{table}
\caption{The effects of treatments X and Y on the four groups studied.}
\label{tab:treatments}
\centering
\begin{tabular}{l l l}
\toprule
\tabhead{Groups} & \tabhead{Treatment X} & \tabhead{Treatment Y} \\
\midrule
1 & 0.2 & 0.8\\
2 & 0.17 & 0.7\\
3 & 0.24 & 0.75\\
4 & 0.68 & 0.3\\
\bottomrule\\
\end{tabular}
\end{table}
```

You can reference tables with `\ref{<label>}` where the label is defined within the table environment. See `Chapter1.tex` for an example of the label and citation (e.g. Table 1.1).

TABLE 1.1: The effects of treatments X and Y on the four groups studied.

Groups	Treatment X	Treatment Y
1	0.2	0.8
2	0.17	0.7
3	0.24	0.75
4	0.68	0.3

1.7.5 Figures

There will hopefully be many figures in your thesis (that should be placed in the *Figures* folder). The way to insert figures into your thesis is to use a code template like this:

```
\begin{figure}
\centering
\includegraphics{Figures/Electron}
\decoRule
\caption[An Electron]{An electron (artist's impression).}
\label{fig:Electron}
\end{figure}
```

Also look in the source file. Putting this code into the source file produces the picture of the electron that you can see in the figure below.

FIGURE 1.1: An electron (artist's impression).

Sometimes figures don't always appear where you write them in the source. The placement depends on how much space there is on the page for the figure. Sometimes there is not enough room to fit a figure directly where it should go (in relation to the text) and so LaTeX puts it at the top of the next page. Positioning figures is the job of LaTeX and so you should only worry about making them look good!

Figures usually should have captions just in case you need to refer to them (such as in Figure 1.1). The `\caption` command contains two parts, the first part, inside the square brackets is the title that will appear in the *List of Figures*, and so should be short. The second part in the curly brackets should contain the longer and more descriptive caption text.

The `\decoRule` command is optional and simply puts an aesthetic horizontal line below the image. If you do this for one image, do it for all of them.

LaTeX is capable of using images in pdf, jpg and png format.

1.7.6 Typesetting mathematics

If your thesis is going to contain heavy mathematical content, be sure that LaTeX will make it look beautiful, even though it won't be able to solve the equations for you.

The "Not So Short Introduction to LaTeX" (available on CTAN) should tell you everything you need to know for most cases of typesetting mathematics. If you need more information, a much more thorough mathematical guide is available from the AMS called, "A Short Math Guide to LaTeX" and can be downloaded from: `ftp://ftp.ams.org/pub/tex/doc/amsmath/short-math-guide.pdf`

There are many different LaTeX symbols to remember, luckily you can find the most common symbols in The Comprehensive LaTeX Symbol List.

You can write an equation, which is automatically given an equation number by LaTeX like this:

```
\begin{equation}
E = mc^{2}
\label{eqn:Einstein}
\end{equation}
```

This will produce Einstein's famous energy-matter equivalence equation:

$$E = mc^2 \tag{1.1}$$

All equations you write (which are not in the middle of paragraph text) are automatically given equation numbers by LaTeX. If you don't want a particular equation numbered, use the unnumbered form:

```
\[ a^{2}=4 \]
```

1.8 Sectioning and Subsectioning

You should break your thesis up into nice, bite-sized sections and subsections. LaTeX automatically builds a table of Contents by looking at all the `\chapter{}`, `\section{}` and `\subsection{}` commands you write in the source.

The Table of Contents should only list the sections to three (3) levels. A `chapter{}` is level zero (0). A `\section{}` is level one (1) and so a `\subsection{}` is level two (2). In your thesis it is likely that you will even use a `subsubsection{}`, which is level three (3). The depth to which the Table of Contents is formatted is set within `MastersDoctoralThesis.cls`. If you need this changed, you can do it in `main.tex`.

1.9 In Closing

You have reached the end of this mini-guide. You can now rename or overwrite this pdf file and begin writing your own `Chapter1.tex` and the rest of your thesis. The easy work of setting up the structure and framework has been taken care of for you. It's now your job to fill it out!

Good luck and have lots of fun!

Guide written by —
Sunil Patel: www.sunilpatel.co.uk
Vel: LaTeXTemplates.com

Chapter 2

Introduction

2.1 Creative Introduction

Search and find, order and pay, evaluate and reclame - alltogether, nowadays, only one click away. The final step, however, deliver the parcel to the customer remains a process that lasts for days. While digital revolution has been providing extensive flexibility due to an information exchange at the speed of light, traditionally grown structures operating in real world have not been able to follow such an acceleration and will never be due to physical constraints. Nevertheless, great advancements in parcel shipping are in sight. From globally operating companies down to start ups as well as universities and research centers are doing research on solutions to parcel delivery by unmanned aerial vehicles (UAV) in order to drastically reduce delivery time and costs. Besides, due to vast, further research, many other areas of applications for UAV technology has been arising, e.g. aerial surveillance, monitoring of existing architectures. Due to strong benefits of UAV technology, e.g. cost efficiency, process optimization, sustainability, independence of infrastructure, etc., UAV technology likely will establish in daily life and industry. However, UAV technology has yet gone into action only sporadically waiting for its breakthrough.

The breakthrough is closely coupled with achieving high robustness of autonomous flight. Guaranteeing safety at high speeds and high flight performance, is crucial to responsibely and economically apply autonomous UAV technology exspecially in areas with human civilization.

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Chapter 3

Literature Review

For the last few years numerous, newly developed UAV technologies have been successfully applied in industry and projects of public interest. Meanwhile, major companies and research centers across the globe are researching on further UAV based solutions. Employing the benefits of machine learning, new approaches for autonomous navigation that outperform traditional approaches have been published. Still, the robustness of autonomous systems is not sufficient to safely deploy them in many, desired areas of application. Increasing the level of autonomy and improving robustness, e.g. enable UAVs to safely operate in dynamic environments like urban areas, is thus, most significant for further integration of UAV technologies into public life.

This chapter ...

3.1 Unmanned Aerial Vehicle

This section provides a definition for the term of an unmanned aerial vehicle (UAV) and introduces common classification approaches in order to subsequently integrate the quadcopter MAV which I am going to deploy within the research of my master thesis.

An unmanned aerial vehicle (UAV), often referred to as drone, is an aircraft without a human pilot onboard. Core components of an UAV are an airframe, an autopilot, onboard sensors and data link. While the airframe constitutes the mechanical structure, the autopilot is the fundamental control unit of an UAV. It translates higher control commands, e.g., to track a trajectory, into individual motor commands and autonomously performs basic navigation tasks, e.g., to stabilize the aircraft or to maintain the pose, as support to a human pilot or as part of a preprogrammed mission or of an fully autonomous control structure. Onboard sensors such as an inertial measurement unit (IMU), a satellite-based navigation sensor, a video camera or a light detection and ranging (LIDAR) sensor, supply the autopilot and optionally existing, superior control units, with the necessary data input. Data link enables the UAV to exchange digital information. Optional components of an UAV, e.g., a companion computer for increased computational power, can be mounted onboard. One or more UAVs, combined with one or more ground control stations (GCS), form an unmanned aerial system (UAS). At the GCS, data from the UAV is processed and the UAV is either steered by human pilot or instructed to fly a preprogrammed mission or autonomously. While the quadcopter is the best-known representative, various different types of UAVs exist which are classified by means of different criteria, i.e., airframe type and key characteristics. **Fahlstrom2012** However, a universal, international classifying system does not exist.

3.1.1 Classification by Airframe Type

Airframe type and the particular configuration of an UAV have big impact on its capabilities to navigate in various applications and environments. **Kong2010** Austin introduces three main categories of airframe types, i.e. horizontal take-off and landing (HTOL), vertical take-off and landing (VTOL) and hybrids. **Austin2011** **HTOLs** are foremost represented by airplanes which are composed of fixed wings and a propulsion unit. When moving forward, the wings generate lift that compensates gravitational force by accelerating horizontally incoming air downwards. The wings also have stabilizing effects on the aircraft and hold control surfaces that enable navigation. HTOL is the most aerodynamically efficient airframe configuration and therefore, suitable for missions with high speed as well as long flight range and time. Since lift generation depends on forward motion, a HTOL cannot maintain position and its launching and landing require infrastructure, either a runway or a launch and recovery system. Thus, HTOLs cannot be deployed on missions which entail hovering or lack launching and landing infrastructure, e.g., business-to-customer (B2C) delivery in densely populated areas. **VTOLs** are foremost represented by copters wich are composed of a single or multiple rotors. A copter generates lift by rotating its rotor(s) and accelerating air downwards. Since the air is drawn in from above the rotor(s), a copter is able to hover as well as launch and land vertically. Besides vertical force, a running rotor induces also torque on the aircraft. In case of a helicopter (single rotor copter), an additional, small tail rotor cancels the torque of the main rotor and stabilizes the yaw of the aircraft. In case of a multicopter, the torques counter themselves due to the fact that individual rotors are arranged in opposite directions of rotation. Depending on particular aircraft design, navigation is achieved by adjusting either rotational speed or tilt of constituent rotors in order to generate differential thrusts and torques. At the prize of lower flight speed, range and time, VTOLs are suitable in situations which require hovering as well as launching and landing on small areas without previously installed infrastructure. **Hybrid Systems** combine benefits of HTOLs and VTOLs, i.e., the ability of vertical take off and landing as well as the speed necessary for long range and high altitude flights. This is usally realized by either 90 degree tilting rotors or an array of 90 degree tilting jets mounted on the fixed wings and fuselage of a HTOL.

3.1.2 Classification by Key Characteristics

Official authorities published various classification systems for UAVs with respect to technical specifications and key characteristics. Most of the classification systems come from the military sector, e.g., the five UAS groups based on maximum gross takeoff weight, normal operating altitude and airspeed published by the United States Department of Defense **USDOD2011** But there also exists classification for the civil realm, e.g., the seven classes based on empty weight, take-off weight and usage published by the Civil Aviation Administration of China **Wei2016** Watts, Ambrosia and Hinkley**Watts2012** propose a classification for civil, scientific usage. Mentionable UAV classes of their classification are micro air vehicles (MAV), low altitude, short endurance (LASE), low altitude, long endurance (LALE), medium altitude, long endurance (MALE) and high altitude, long endurance (HALE). For their key characteristics, see table 3.1.

TABLE 3.1: Classification of UAVs in the civil realm by Watts, Ambrosia and Hinkley. **Watts2012**

Class	Altitude	Endurance	Range	Takeoff / Landing
MAV	< 330 m	< 30 min	< 1 km	Any small area
LASE	< 450 m	< 2 h	< 10 km	Human hand, catapult system or runway
LALE	< 5,000 m	< 20 h	< 100 km	Runway
MALE	< 9,000 m	< 40 h	< 1,000 km	Runway
HALE	< 25,000 m	< 30 h	< 10,000 km	Runway

3.1.3 The Quadcopter MAV for my Research

For the research within my master thesis, I have two quadcopter MAVs at hand which differ only in the fact that one of them has an additional companion computer.

FOTO

The quadcopter configuration is the most common airframe for UAVs in the civil realm. For all multicopters, electronic complexity in form of multiple motors, speed controllers and a power distribution board as well as an autopilot, which computes individual motor speeds in order to stabilize the aircraft and follow navigation inputs, replace the mechanical complexity of helicopters. However, due to extensive cost decrease and performance increases from the year of 2000 on, huge markets and broad research on UAVs, exspecially multicopters, have been established.

However, the insights of my master thesis will be reproducible for other configurations of multicopters because my research takes place on a higher level of navigation control. and low level control of individual motors is excluded. Thus, common autopilots can cancel the differences between the various configurations of multicopters and can ensure an essentially similar flight behaviour.

3.2 Navigation of an Autonomous Quadcopter

HERE

3.2.1 Low-level control by Autopilot

HERE

3.2.2 High-level control

< They can be controlled by onboard electronic equipments or via control equipment from the ground. When it is remotely controlled from ground it is called RPV (Remotely Piloted Vehicle) and requires reliable wireless communication for control. Dedicated control systems may be devoted to large UAVs, and can be mounted aboard vehicles or in trailers to enable close proximity to UAVs that are limited by range or communication capabilities. >

Human Pilot <When it is remotely controlled from ground it is called RPV (Remotely Piloted Vehicle) and requires reliable wireless communication for control.>

3.3 Civil Applications of Multicopters

UAV technology has historic origin in military affairs from the 1930's. They had been mostly confined to military use until around the year of 2000, when along with rapid performance improvements, costs of electronic components have been essentially decreasing which made UAV technologies accessible for the wider public. A huge UAV market for private customers has been established. Many UAV manufacturing companies have been founded which today, operate in this worldwide business.

OPEN SOurce Projecte

They have been producing numerous innovative UAV designs, concepts and algorithms which in turn around the year of 2015, opened the door to industry applications and projects of public interest for UAV technologies.

This section introduces these fields of applications in order to demonstrate the value to society that UAV technology has already achieved. Moreover, the potential of UAV technology in future applications is discussed, as well as factors that limits the breakthrough into daily life and the research to eliminate these factors. Thereby, the focus is on business-to-customer (B2C) UAV delivery which is one of the most relevant future applications for UAV technology and whose prosperous established relies foremost on the realization of robust, autonomous flight in dynamic environments - a topic this work should contribute.

UAVs are exspecially useful on missions which are either characterized as dangerous, i.e. "human pilot operations would be at a disadvantage or at high risk" **Watts2012** or as inefficient human pilot. surveillance - cost efficient data gathering together with big data and cloud computing.

3.3.1 Passenger Transport

3.3.2 Freight Traffic

3.3.3 Agriculture

According to PwC, one of the largest professional services firms, broader application of UAV technologies in agriculture is partial solution to satisfy increasing agricultural consumption in light of the predicted growth of world's population over the next decades. In this sense, JD.com, the second biggest Chinese online retailer and pioneer in UAV and smart technology, launched the initiative, "JD Smart Agriculture Development Community" with the aim to "increase the efficiency of China's agriculture industry" and "raise the overall level of food safety and quality". With the help of JD-X, JD.com's logistics innovation lab, UAV technology is deployed for crop protection, i.e. to "monitor and analyze water, soil, pesticides, fertilizer, weather, diseases and pests".

Currently, UAVs operate in the fields of soil and field analysis, planting, crop spraying, crop monitoring,

< 1. Soil and field analysis: Drones can be instrumental at the start of the crop cycle. They produce precise 3-D maps for early soil analysis, useful in planning seed planting patterns. After planting, drone-driven soil analysis provides data for irrigation and nitrogen-level management.

2. Planting: Startups have created drone-planting systems that achieve an uptake rate of 75 percent and decrease planting costs by 85 percent. These systems shoot pods with seeds and plant nutrients into the soil, providing the plant all the nutrients necessary to sustain life.

3. Crop spraying: Distance-measuring equipment— ultrasonic echoing and lasers such as those used in the light-detection and ranging, or LiDAR, method— enables a drone to adjust altitude as the topography and geography vary, and thus avoid collisions. Consequently, drones can scan the ground and spray the correct amount of liquid, modulating distance from the ground and spraying in real time for even coverage. The result: increased efficiency with a reduction of in the amount of chemicals penetrating into groundwater. In fact, experts estimate that aerial spraying can be completed up to five times faster with drones than with traditional machinery.

4. Crop monitoring: Vast fields and low efficiency in crop monitoring together create farming's largest obstacle. Monitoring challenges are exacerbated by increasingly unpredictable weather conditions, which drive risk and field maintenance costs. Previously, satellite imagery offered the most advanced form of monitoring. But there were drawbacks. Images had to be ordered in advance, could be taken only once a day, and were imprecise. Further, services were extremely costly and the images' quality typically suffered on certain days. Today, time-series animations can show the precise development of a crop and reveal production inefficiencies, enabling better crop management.

5. Irrigation: Drones with hyperspectral, multispectral, or thermal sensors can identify which parts of a field are dry or need improvements. Additionally, once the crop is growing, drones allow the calculation of the vegetation index, which describes the relative density and health of the crop, and show the heat signature, the amount of energy or heat the crop emits.

6. Health assessment: It's essential to assess crop health and spot bacterial or fungal infections on trees. By scanning a crop using both visible and near-infrared light, drone-carried devices can identify which plants reflect different amounts of green light and NIR light. This information can produce multispectral images that track changes in plants and indicate their health. A speedy response can save an entire orchard. In addition, as soon as a sickness is discovered, farmers can apply and monitor remedies more precisely. These two possibilities increase a plant's ability to overcome disease. And in the case of crop failure, the farmer will be able to document losses more efficiently for insurance claims. >

3.3.4 Healthcare

3.3.5 Environmental Protection

3.3.6 Delivery service

Watts2012

Introduction tests are being conducted, what big companies and startups are doing, and where it is possible to see the technology in action.

For a few years the idea of delivery drones transporting parcels, food and other goods directly to customers has manifested in several pioeneer applications. Researchers are working hard on this hot topic which will reduce delivery time, costs.

Potential Drone delivery technologies have big potential of improvements in various aspects.

From economic considerations, drone delivery is a better solution to the "last mile problem" which refers to the high costs occurring during the last, inefficient step of supply chains. On short distances from a transportation hub to final destinations, drones can be faster while consuming less fuel. Costs related to traditional delivery on the "last mile" such as <labor costs for human drivers> and <fleet maintenance of commercial vehicles> are omitted. https://www.statista.com/statistics/816884/last-mile-delivery-logistics-providers-challenges/

In the field of healthcare, drones show promise to speed up emergency response where the time from incident to first measure is most critical and congestion might be fatal. Hastening the supply of emergency medicine, donated blood and portable medical devices as well as enabeling paramedics to instruct helpers on site from a far distance is life saving in case of misfortunes like heart attacks, strokes and external injuries.

Because drones are electrically powered, they provide benefits with respect to climate protection if batteries are recharged with renewable resources. Moreover, the operation of drones is emmision-free and thus, an answer to the air pollution problems which occurs in metropoles across the globe [QUELLEN Deutschland, China, Indien, USA].

<overcoming delivery problems to remote areas>

Applications The concept of commercial drone delivery started in 2013 when Amazon announced their initiative "Amazon Prime Air" of developing drone systems for parcel delivery.

Within less than a week, UPS reacted on the new competitor in its core business with announcing their own plans of drone delivery.

Trapped by regulations

FAA rules currently prohibit drone flights that are entirely autonomous or beyond the line of sight of human operators. 7-Eleven has managed to work within those regulations by using its delivery service as a means to advance research toward integrating drones into the National Airspace System, while also helping further refine Flirtey's delivery technology.

Nevertheless, in the shadow of these gigantic players, in July 2015 Flirtey, an Australian start-up, performed the first federally-approved commercial drone flight in the U.S.

Thereupon in July 2016, Flirtey in corporation with the convenience store chain 7-Eleven performed the first "store-to-door" drone deliveries to private customers in the US with an autonomously flying drone relying on precision GPS.

In December 2016, Amazon caught up with its first drone delivery in the UK. <drone flights that are entirely autonomous or beyond the line of sight of human operators, The UK and several other countries have taken more pro-innovation regulatory positions Amazon chose the country with a regulatory climate that is more conducive to proper UAV testing and subsequent application >

In August 2017, the icelandic start-up Aha in corporation with Israeli logistics system Flytrex started a project to fly drones manufactured by the biggest Chinese drone company DJI on preprogrammed missions to deliver consumer goods to customers' houses in Rejkjavik the capital of Iceland. Iceland previously opened its regulations for this project. **Ross2018**

October 2016 Zipline

With its huge population (1.4 billion people in 2018) eCommerce Report and broad social acceptance towards digital innovations -in comparison 39% of US American citizens are sceptical towards drone delivery https://www.statista.com/chart/5843/level-of-trust-in-drone-delivery-services/-, China surpassed the United States of America in 2013 and became the biggest eCommerce market worldwide with a total revenue of approximately 633.9 billion USD in 2018 leaving the US on second place with 501.0

billion USD and the European Union on third place with 358.1 billion USD. eCommerce Report https://www.techinasia.com/2013-china-surpasses-america-to-become-worlds-top-ecommerce-market https://www.statista.com/study/42335/ecommerce-report/

The growth of eCommerce has strong impact on the logistics market demanding innovative and efficient approaches for fast and reliable door step parcel delivery shipment even in remote areas with little infrastructure.

logistic companies. The China-based companies DJI, ... are among the biggest drone developers and producers and came up with highly engineered, innovative drone systems. For individuals as well as in corporation with the dominating shipment companies JD, SF Express, in China.

Several China-based companies are testing drone delivery supported by innovative drone comanies such as DJI.

https://www.scmp.com/tech/innovation/article/2129585/jdcoms-autonomous-delivery-vehicles-will-take-streets-tianjin-june After the approval by the China Civil Aviation Administration <build tens of thousands UAV landing platforms or drone pods across China> JD.com extended its drone projects with own UAV, unmanned ground vehicles, and unmanned warehouses within its JDX Department for intelligent logistics. https://technode.com/2018/02/05/e-commerce-giant-jd-will-build-tens-of-thousands-delivery-drone-landing-pods/ https://jdcorporateblog.com/jd-com-announces-series-of-new-agreements-for-drone-development/ https://jdcorporateblog.com/jd-com-to-build-largest-drone-logistics-network-and-rd-campus-in-china/

While the logistics subsidiary of JD.com which is the second biggest business to customer (B2C) eCommerce company in China after Tmall of the Alibaba Group was opening its first UAV distribution center in Haikou, the capital of Hainan in 2018, the first company that received a license for drone delivery services by responsible Chinese administration was Jiangxi Fengyu Shuntu Technology Company. The company is an affiliated company of SF Express which is one of the biggest delivery service companies in China An airborne supply chain consisting of nationwidely operating planes, locally distributing larger drones and customer delivering smaller drones should foremost increase the coverage of delivery and the delivery time in rural areas.

< Its first drone took off on 26 March on its way to the company's first Hainan delivery (in Chinese). Hainan is an island off the southern coast of the mainland and is highly mountainous and so a suitable testing ground for the format. JD has ambitions to be able to deliver anywhere in the country within 24 hours.>

International Corporation with Rakuten in Japan Indonesia

JD.com Alibaba <This Chinese company is pursuing a massive and rapid expansion of a commercial drone delivery system in the four most-populated provinces in China. The drones fly from centralized warehouses to locally-designated landing pads. More than 300,000 local delivery operators then take the packages to the nearby homes. This company has small commercial drones that can fly up to 62 mph (100 kph) and carry up to 66 lbs. (30 kg). It also has a very large commercial drone that can carry up to one metric ton (2,200 lbs.). > DHL In December of 2013, DHL started delivering medicines using drones in Germany.

Alibaba In February 2015, Alibaba partnered with the courier company Shanghai YTO Express to deliver tea by commercial drones to 450 customers in certain Chinese cities.

Alphabet (Google)

Google has many ongoing drone programs and tests underway including Alphabet X, which partnered with Chipotle Mexican Grill to deliver food to the cafeterias on the Virginia Tech Campus. Since 2014, Alphabet X has been testing drone delivery service ins Australia to deliver both consumer items and much heavier things such as building materials. Project Wing delivers medicines and burritos in rural areas.

Limiting factors The breakthrough of drone delivery has not been taken place yet due to several limiting factors.

In contrast to the previously mentioned environment-friendly abilities, current, typical drone models emit a buzzing noize. Thus, an extensive application of drone delivery, would lead to new, dominant source of noise pollution which affects the quality of life in urban areas.

Safety Concerns - include damage and injury caused by accidents, flyaways, privacy issues, security, and package interference from stealing or vandalism.

Due to little experience of drones participating in daily traffic, consequences of traffic accidents caused by drones are difficult to predict. There have not been recorded any fatal commercial drone crash until now ???and the risk of autonomous flight is estimated very low ????? but a lot of near-accidents and injuries are reported . Not least because of the uncontrolled nature of drone crashes, the deploy of drone technologies in daily life is seen critically by local administrations and is legally restricted by local laws of the states. ??autonomous and human pilot.?? To give a few examples, in the United States of America, law forbids the navigation of drones above other persons Quelle!!!(December 2018) In cities, drone delivery would be only legally possible on air corridors for drones and would lose its advantage of not being bound to existing infrastructure and thus, could be affected by congestion and circuitous routes. Moreover, according to the Federal Aviation Administration (FAA) in the United States, out-of-sight drone navigation with a virtual reality headset needs a special permission which further limits drone delivery in not fully visible delivery areas like cities. autonomous???

Privacy is another concern when it comes to drone navigation and led to legal restriction. Drone systems are equipped with different sensors, visual, range, can look through walls etc. and would enter spheres which until now have not been reached by them. A single drone can look through windows at high levels or see what happens behind a tall fence. A whole fleet of delivery drones can profile entire societies if their data is combined and evaluated with methods of artificial intelligence.

By law, unauthorizedly overflying restricted areas of critical infrastructure such as nuclear power plants and military bases is forbidden. Losing control of drones in case of navigation failure or hacker attack can be punished by heavy fines or even imprisonment.

Another concern is the security of delivered items which decisively affects the consumers to accept this new way of delivery. Finding convenient solutions to criminal actions such as the downing of drones or the stealth of delivered parcels as well as technical questions, e.g. protection of the parcel against rain and outer forces as well as a robust approach of handing it over, are crucial here.

<Realistically, however, implementation could take three to five years, and that's just to get FAA approval. There may be other problems, too, in densely populated cities like Washington D.C. where no-fly zones are currently in place.

Brendan Schulman, special counsel at Kramer Levin Naftalis and Frankel LLP told the Associated Press:

The technology has moved forward faster than the law has kept pace.>

Current Research Current research on Future Solutions

noise pollution problem, Edgar Herrera, developed a blade-less drone. It flies in complete silence. The drone is not yet in production; however, the design is spectacular. Solar-powered, silent-flying, drone delivery is a really great idea that takes this whole concept to the next level. In the future, there may be overly-active, drone-flying corridors that are constantly buzzing.

Legal restrictions with more robust technology. <Using drones equipped with emergency parachutes, which automatically deploy for power losses, can help reduce crash damage and injuries. There are plenty of opportunities for entrepreneurs to improve drone-flying safety. >

<Drones equipped with video surveillance technology can reduce these criminal risks; however, these cameras cause privacy and security issues to arise. This is an area of opportunity, where entrepreneurs can focus on providing solutions. >

already capable of being deployed for many types of delivery services such as pizzas in urban environments and desperately-needed medicine flown by drones to remote inaccessible villages.

already plenty of opportunities flying unmanned aerial vehicles (UAVs) for fun and for professional uses.

3.3.7 Entertainment

3.3.8 Power and Utilities Industry

3.3.9 Passenger Transport

3.3.10 Cellular Connectivity

3.3.11 Civil Engineering

<rescue, exploration, environment monitoring, map construction or search>

3.4 Autonomous Navigation Systems of Small Quadcopter UAVs

For legal classification and restriction, the International Civil Aviation Organization (ICAO) devides UAVs into either fully remotely controlled or fully autonomous. From technical perspective, autonomy is not a static but a fluent feature of an UAV and thus, more precisely referred to as degree of autonomy. For example, even a remotely piloted vehicle (RPV) usually involves an autopilot which supports the human pilot during flight by autonomously performing tasks, e.g. maintaining pose. This section recaps a general concept of autonomy as well as a hierarchical control architecture for a fully autonomous UAV in order to subsequently introduce autonomous navigation systems of UAVs. Traditional and newly developed methods related to autonomous navigation as well as the research of this work are classified.

3.4.1 Dynamics and Control

During flight, an UAV is an unstable system and requires continual control. Traditionally, this control is engineered on multiple control levels. **QUELLE** (except some end-to-end learning control methods). While on a lower control level, an onboard autopilot is permanently maintaining attitude and altitude of the UAV in order to prevent collisions and keep up maneuverability, on a higher level, different actors can navigate the drone and perform maneuvers. Either a human pilot steers the UAV remotely from the GCS per radio transmitter (RC) thereby, relying on direct visual contact to the vehicle or on video stream from an onboard camera, or an onboard computer constantly executes algorithms to track trajectories thereby, relying on sensor data. While traditional navigation approaches, such as VIO or SLAM evaluate sensor data received from GPS, radio, inertial, SLAM, VIO to estimate the pose of the UAV, new approaches basing on camera or LIDAR data utilize perception concepts of machine learning. These computer tracked trajectories are either static, as part of a precomputed mission or adaptive to dynamic environments in sense of autonomous flight.

3.4.2 Autonomous Flight

Ability to avoid obstacles static and dynamic???

3.4.3 Autonomy

The concept of autonomy extends automation onto unexpected situations. Automation replaces human action to complete well known tasks in well known, structured environments. While an automated system outperforms humans with respect to precision, speed and costs, it is unable to cope with unexpected situations since it is engineered to rely on limited parameters, variations and disturbances. In addition to an automated system, an autonomous system, due to a deeper based perception, is capable of anticapating upcoming events, making decisions and reacting properly - like humans. It can perform previously unknown tasks in previously unknown, dynamically changing environments, deal with uncertainty and learn from its failures. The design of an autonomous system requires the composition of various methods from control theory, system identification, system estimation, communication theory, computer science (in particular artificial intelligence) and operations research. Furthermore, with machines making decisions, questions of other fields concerning ethics, responsibility, legality arise.

3.4.4 Hierarchical Control Architecture of a Fully Autonomous UAV

In contrast to RPV...

Involving the concept of increasing precision with decreasing intelligence (IPDI), control architectures of autonomous systems for UAVs can be functionally layered into three control levels, i.e. organization, coordination, and execution as well as a supervisor level to enable human intervention.

Downstream, from higher to lower levels, commands are distributed and system parameters are modified.

Upstream, from lower to higher level, command responses and sensor data are passed.

Information may also be exchanged within the same level.

The higher the control level, the longer the interval of planning and execution time.

All three levels have access to information about environment and state estimates of the UAV.

The least intelligent **execution level** interfaces with sensors and actuators of the UAV. While receiving sensor data about the state of the UAV and the environment, this level runs conventional control algorithms on inner-loop and sends low level control commands directly to the actuators of the UAV.

(These algortightms very good researched)

It senses the responses of the vehicle and environment, processes them to identify parameters, estimates states, or detects failures, and passes this information to the higher levels.

Organization Level highest intelligent and lowest precision involves intelligent, decision-making methods, situation evaluation and mission management.

Coordination Level The middle level interface between the actions of the other two levels combination of conventional and intelligent decision making methods. outer-loop

middle-loop to generate the trajectory, guidance and other signals

3.4.5 Autonomous Navigation Systems for Small Quadcopters

Flight Control Pipeline

Classical System Architecture Env - Sensor - State (Velocity) Estimation - Velocity Controller - Flight Controller - Motors - obstacle detection - local planner - position controller -

Camera Based System Architecture For Reactive Flight Control Pipeline

System Architecture For Fully End-to-End LIDAR Based Reactive Flight Control Pipeline

LIDAR to Actions System Architecture QUELLE SAMZENG

In case of a small UAV, one major point is to guarantee that the algorithms can be executed in real time since onboard hardware is constrained by small payloads.

Challenges < There has been many significant research in making UAV fly autonomously, but obstacle avoidance is still a crucial hurdle. For small quadrotor UAV, due to the limitation of payloads it is infeasible to carry sophisticated radar sensors. Though many advanced research has used light detection and ranging(LiDAR) [1] or the cameras of Microsoft Kinect [2], both sensors are heavy, which will lead to increase the power consumption and drastically decrease the flight time. > SOURCE

< Autonomous flight is in contrast to other control methods, i.e. radio remote and preprogrammed. communication link is not expedited or reliable doesn't update mission when plans or treat situations are changed rapidly changing uncertain environment the present techniques are inadequat

perform well under significant uncertainties inthe system and environment for extended periods of time compensate for system failures without external intervention

techniques from the field of Artificial Intelligence (AI) evolve from conventional control systems by adding intelligent components, and their development requires interdisciplinary research [3].

Autonomous controllers have the power and ability for self governance in the performance of control functions. high degree of automation is applied in a very unstructured environment “Automation” here refers to the absence of human intervention, “unstructured environment” is associated with uncertainty

integrates concepts and methods from areas such as Control, Identification, Estimation, and Communication Theory, Computer Science, especially Artificial Intelligence, and Operations Research (OR). The synthesis of high performance controllers for the solution of difficult control problems is what autonomous control is really all about.

>

3.4.6 Traditional Approaches

HERE

3.4.7 Newly Developed

HERE

Due to the inherent instability of the system, constant control commands must be applied to prevent a collision. In the event the robot enters an environment where **accurate state estimation** is computationally impossible due to lack of features, we still want the system to do its best given available information to prevent immediate collision.

3.5 Drone Racing

Chapter 4

Research Objective

Classification of research program(national program, local government program, industrial program, university program, self-selected topic or others):

4.1 Anticipated Contribution

Global vs local planning. -> Local planning with advantages of optimization of global strategies.

4.1.1 Subsection 1

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4.1.2 Subsection 2

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4.2 Research Plan

The research plan is devided into three main categories which are the framework for experiments in simulation, the framework for experiments in real world and the perception and planning algorithm.

4.2.1 Framework for Experiments in Simulation

- Build race track.
- Compute global trajectory.
- Track global trajectory.
- Implement data link (onboard camera)

- Implement automized training of neural network.
- Implement test scenarios.

4.2.2 Framework for Experiments in Real World

- Find location and build race track.
- Deploy localization algorithm.
- Run hardware.
- Safety regulations.
- Finance.
- Compute global trajectory.
- Track global trajectory.
- Implement data link (onboard camera)
- Implement automized training of neural network.
- Implement test scenarios.

4.2.3 Perception and Planning Algorithm

- Develope algorithm
- Design neural network
- Implement algorithm
- Optimize efficiency for onboard execution

Scheduled time of completion of reading and investigation: Scheduled time of completion of research work: Equipment for experiment and other research facilities

4.3 Methodology and Elaboration

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4.4 Solutions

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4.5 Schedule of Thesis Writing and Proposed Date of Defense

I intend to complete the research, which includes programming solutions as well as conducting tests in simulation and real world, until the mid of December 2019, when I am going to return to Germany. If points of the research plan will not have been complied by then, I am going to finalize them at the Technical University of Berlin starting from New Year on. Directly after, I am going to start writing my master thesis. At my present discretion, I will finalize the thesis until the end of February 2020.

According to the regulations of the Double degree master of ————————- I am going to achieve remaining credits in September, by the end of the spring semester 2020. Subsequently, having all requirements of the program fulfilled, I am going to do my final defense in October 2020 either by appearance in person or video conference.

Outline of the thesis and schedule of thesis writing:

Appendix A

Frequently Asked Questions

A.1 How do I change the colors of links?

The color of links can be changed to your liking using:
`\hypersetup{urlcolor=red}`, or
`\hypersetup{citecolor=green}`, or
`\hypersetup{allcolor=blue}`.
If you want to completely hide the links, you can use:
`\hypersetup{allcolors=.}`, or even better:
`\hypersetup{hidelinks}`.
If you want to have obvious links in the PDF but not the printed text, use:
`\hypersetup{colorlinks=false}`.

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