Studying Geodesy and Geoinformatics - a German university perspective

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Abstract

This paper describes the discipline of geodesy and geoinformatics with a focus on university studies and career opportunities. It is shown how the disciplines contributes to the solutions of major societal challenges such as sustainable development, mobility and global change. Then, the structure of German universities is shortly explained, followed by an overview of where in the country the discipline can be studied. Finally, the example of Leibniz University Hannover, one of the prime centres of excellence in the field, is described in more detail. We thus hope to encourage young talents to consider this exciting field of studies for their future career.

1. Introduction

1.1 Geodesy and Geoinformatics

Traditionally, *geodesy* was defined as the „the science of the measurement and mapping of the Earth's surface" (Helmert, 1880). During the 20th and the first decades of the 21st century, this definition has been extensively enlarged, mainly due to the development of space technology, digital sensing systems, and ICT: information and communication technology. Today, while in the English and French speaking world, the term *geodesy* is linked to the observation of the Earth as a whole and treats questions about the figure and rotation of the Earth, global geodetic reference systems and the gravity field, in the German language a more comprehensive understanding of the term is commonplace, incl. also land surveying, photogrammetry, remote sensing, cartography and land management together with its modern developments such as navigation, computer vision, spatial databases, augmented/virtual reality, visual analytics and geospatial artificial intelligence (GeoAI). This wider understanding of *geodesy* is sometimes underlined by the term *geodesy and geoinformatics* or *geomatics* (G&G). It is this more general field which is the background of this paper, in which possibilities to study geodesy in Germany are explored with the specific example of the author's home university, Leibniz University Hannover.

Geodesy is an engineering discipline with strong relations to mathematics and natural sciences on the one side, and to geo- and social sciences on the other (see Figure 1). According to a definition published by the German Geodetic Commission DGK, this discipline "acquires data about the Earth and its various spheres of life, including their changes in different spatial and temporal scales; and it analyses, interprets, visualizes, documents and evaluates the captured data. Finally, geodesy models, simulates and designs developments based on different scenarios and supports decision processes. In this way, geodesy creates an indispensable highly accurate, as well as up-to-date and reliable data and information base about the Earth and distributes this information via efficient geospatial data infrastructures to other disciplines. Furthermore, geodesy draws conclusions in an interdisciplinary context (…) and designs strategies for sustainable development and change management" (Heipke 2013, p. 1).

It is often said that 80% of all decisions have a spatial component. Reliable and up-to-date geoinformation, which is the result of geodetic activity, is considered to be an essential digital infrastructure of a modern nation, equally important as traffic, electricity, telecommunication, water and sewage infrastructure. It is dispensable for transparent decision making in government, industry, society, as well as for sustainable development. Geodesists are custodians of global, national and local spatial data infrastructure, as also expressed in the resolution "A Global Geodetic Reference Frame for Sustainable Development", recognising the importance of a globally coordinated approach to geodesy and adopted by the United Nations General Assembly on Feb. 26, 2015 (UN-GGIM, 2015). This resolution "outlines the value of ground-based observations and remote satellite sensing when tracking changes in populations, ice caps, oceans and the atmosphere over time. Such geospatial measurements can support sustainable development policymaking, climate change monitoring and natural disaster management, and also have a wide range of applications for transport, agriculture and construction" (UN-GGIM, 2015). Consequently, *geodesy* is an essential component of many of the 17 Sustainable Developments Goals (SDGs) of the 2030 UN Agenda for Sustainable Development (UN, 2024).

Recent developments of geodesy have been mainly triggered by

1. Fundamental break-throughs in research, e.g., when using quantum sensors in Earth observation, in relativistic geodesy, in the automated acquisition of massive amounts of geospatial data for digitisation, in machine learning for the analysis and use of these "big data".
2. The pressing need for precise geodetic acquisition of local and global change processes in the current climate crisis, e.g., as a base for the Intergovernmental Panel on Climate Change (IPCC) reports and for achieving the UN SDGs.
3. The developments of new digitisation concepts (e.g., national geodata infrastructure, Building Information Modelling, and Industry 4.0) as well as new mobility concepts in the automotive context with decisive importance of geodata and their analysis.

Today, digitisation, mobility and navigation, Earth system sciences, climate change and environmental challenges as well as spatial planning and high precision geometric and physical measurement and data processing are at the core of geodesy. Geodesists analyse spatial information such as imagery, laser data, GNSS signals and Earth gravity measurements, which are acquired using static and mobile platforms, flying drones and

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satellites equipped with various multi sensor systems. Analysis and interpretation of the acquired data is increasingly based on artificial intelligence and machine learning. Applications can be found in areas as diverse as topographic mapping, industrial quality control, 3D city modelling, autonomous driving, environmental monitoring and the determination of sea level rise.

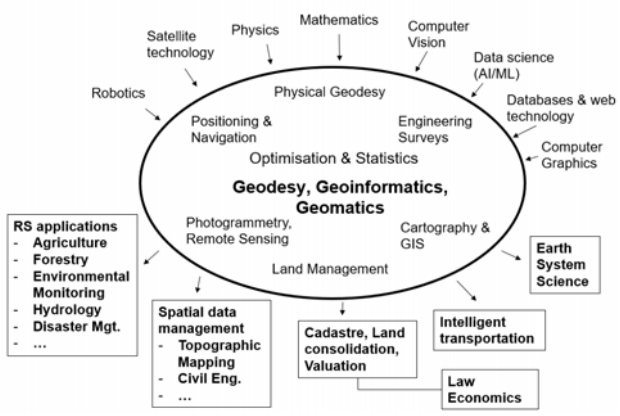

Figure 1.: Geodesy and its relationship to neighbouring disciplines

This enlarged activity implies broader professional perspectives. Geodesy has thus become significantly more attractive, among others by integrating diverse basic and more application-oriented subjects – mathematics, physics and computer science on the one side, and measurement technology, geoinformatics, earth system sciences and land management on the other, to name only a few, see also Fig. 1. A Master’s degree in *geodesy* currently offers excellent career opportunities in a wide field of exciting and well-paid jobs all over the world, in private industry, in research and development as well as in government and public service (see also Arbeitsplatz Erde, 2023). For instance, graduates of the geodesy programme (see Figure 2)

- develop navigation and software systems,
- design high precision 3D measurement and evaluation systems,
- run their own business as a Chartered Surveyor,
- create and sell geoinformation services,
- implement manufacturing and quality control,
- guide construction work and the extraction of raw materials,
- help the automotive industry to build safer and smarter cars, or
- carry out research in aerospace technology, geophysics and related fields.

Another promising option is to obtain further scientific qualification by enrolling in the PhD programme of the university.

2. The German university system

Developed by Wilhelm von Humboldt (1809/10), the classical German university model historically rests on the unity of research and teaching, the development of personality by scientific argument and the rejection of the idea, that university prepares for a career. This was also the basis of education in engineering and technical subjects, which - as in other countries - emerged in concert with the industrial revolution in the 19th century. Higher technical education started e.g., in Berlin in 1821, in Karlsruhe in 1825, in Stuttgart in 1829, in Hannover in 1831, and in Munich in 1868, while the University of Bonn started a surveying programme as part of the agricultural College in the 1880’s.

Following Germany’s federal structure, also the university system is a federal one, which implies that some rules differ from one federal state (“Bundesland”) to another. In general, students enter university after 12 or 13 years of schooling. Most universities are public institutions, and in those - with exceptions for long-term students and for non-European students in some states – students do not pay for university education as tuition fees do not exist.

During the so-called Bologna process, which started some 20 years ago, universities have adopted the Bachelor / Master system of degrees with a total nominal length of five years, each year being divided into two semesters. At Bachelor level, the language for teaching is mostly German, at Master level, programmes are increasingly offered in English.
In general, two types of universities can be distinguished: research universities and so-called universities of applied sciences (“Fachhochschule”). Research universities offering geodesy programmes are characterised by

- programmes leading to the Bachelor (B.Sc.), Master (M.Sc.) and PhD (Dr.-Ing.) degree,
- an in depth focus on more theoretical education with an emphasize on mathematics, physics and computer science,
- a blend of research and teaching from the beginning (and more so in M.Sc. programme),
- a general programme with specialisation tracks at M.Sc. level, e.g., for robotics, navigation or remote sensing,
- the M.Sc. programme being increasingly taught in English,
- an M.Sc. degree, with a seamless continuation into the PhD programme.

The universities of applied sciences, on the other hand, offer

- a larger variety of programmes: mainly B.Eng., (mainly 3,5 y), sometimes followed by M.Eng. (mainly 1,5 years),
- a stronger focus on practical training with a larger number of projects,
- mostly more specialised programmes, sometimes more than one at the same institution,
- little, if any, teaching of physical geodesy,
- in general, no PhD programme, although exceptions start to emerge.

3. Studying Geodesy in Germany

3.1 Location and student numbers

Today, a consecutive Bachelor and Master programme in geodesy is offered by 8 different research universities and 12 universities of applied sciences across Germany (see Figure 3); note that while many of the research universities have adopted the name geodesy and geoinformatics to emphasize the increasing importance of computer science in the programme, the course names slightly differ between the different locations. The research universities in alphabetic order are University of Bonn, TU Darmstadt, TU Dresden, HafenCity Hamburg, Leibniz University Hannover, KIT Karlsruhe, TU Munich and University of Stuttgart. In addition, TU Berlin offers a Master programme in the field.

Figure 2: Examples of application areas of geodesy and geoinformatics

At the level of the universities of applied sciences, geodesy can be studies Berlin, Bochum, Dessau, Dresden, Frankfurt, Karlsruhe, Mainz, München, Neubrandenburg, Oldenburg, Stuttgart and Würzburg.

In the winter semester 2021/22 the number of 1st semester students (Bachelor and Master combined) in the research universities was 533, that of the universities of applied sciences was 743 (Fahrer et al. 2023/24), resulting in 20 - 30 students per semester on average. While these numbers vary from location to location and from year to year, it can be stated that geodesy has a rather small number of students per class compared to other engineering programmes such as civil, electrical and mechanical engineering and thus an excellent professor/student supervision relation.

3.2 Content at research universities

In the following, the focus will be on research universities. Programmes at these institutions are subdivided into the following subjects (DGK, 2018, see also again Fig. 1):

- Engineering Geodesy,
- Positioning and Navigation,
- Physical Geodesy,
- Photogrammetry and Remote Sensing,
- Cartography,
- Land Management,
- Optimization and Statistics.

At B.Sc. level, all these subjects are part of the programme, in addition to a relatively large number of courses in mathematics, physics and computer science; these courses are typically identical for all engineering students. In particular in mathematics and physics, students are required to have a certain knowledge of the subject before entering university in order to follow the lectures. While it is not mandatory to also know a computing language when starting at university, it is certainly an advantage. Besides lectures, lab sessions are offered, where students apply the knowledge gained in the more theoretical lectures and independently solve problems of different degree of complexity, ranging from maths puzzles to a surveying campaign of several days. At M.Sc. level more electives are offered. including seminars, where students discuss and present their work, e.g., different

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approaches published in the international literature, or advanced project work. In this way, students can choose their career path according to their individual interest.

Figure 3.: Locations to study geodesy in Germany (adapted from Fahrer et al., 2023/24)

Nevertheless, the curriculum makes sure that students with a geodesy degree have a general understanding of all parts of the fields. It is also common practice that M.Sc. students are part of research projects conducted by the different university institutes; in these projects students are typically supervised by PhD students. As a consequence, the M.Sc. students are given the opportunity to be exposed to research and thus to the fact, that while open questions exist, answers may not and have to be worked out using theoretical and experimental investigations. The M.Sc. programme ends with a 6 month-long thesis, which is a scientific manuscript, typically of some 60 - 80 pages, documenting the theoretical and experimental work undertaken during the last semester of study, incl. a state-of-the-art chapter, a description of the applied methods and the obtained results as well as an evaluation of the work.

4. Studying Geodesy and Geoinformatics at LUH

4.1 Geodesy and Geoinformatics at LUH

Leibniz Universität Hannover (LUH) is a public research university and a member of the German TU 9 Alliance of Universities of Technology (TU9, 2024). LUH is also a world-leading centre of higher education in Geodesy and Geoinformatics, offering high quality teaching and research. Students at LUH do not pay any tuition fees, graduates enjoy excellent career opportunities in industry, in public service and in research and development worldwide. Over the last decade, LUH was the most successful research university regarding 3rd party funding from the German Research Foundation, staff has excellent publication records and has employed a number of high-ranking positions in international science management.

The LUH offer in geodesy and geoinformatics (LUH_G&G, 2024) is a consecutive accredited three-year B.Sc. and two-year M.Sc. programme. The BSc. programme (LUH_G&G_BSc, 2024) is taught in German and provides students with the basic knowledge in mathematics, physics and computer science as well as the geodesy related subjects listed above. At the end, students write a B.Sc. thesis, in which they have to demonstrate that they are capable of basic scientific thinking and practical problem solving.

4.2 Geodesy and Geoinformatics Master’s Programme

The content of the M.Sc. programme (LUH_G&G_MSc, 2024) builds upon the B.Sc. subjects and lasts for four semesters. Also, the two-year M.Sc. programme is an accredited course, it can be started in autumn (typically around the middle of October) and in spring (normally at the beginning of April). Courses are taught in English and in small groups. International and local students attend the same lectures, making it easy for students from abroad to mingle with German speaking friends and colleagues.

At LUH, three different specialisations are offered:
- Geomatics,
- Navigation and Field Robotics,
- Remote sensing and GIS (scheduled to open in 2025).

Geomatics is basically a continuation of the B.Sc. degree and follows the classical path of the field. Navigation and Field Robotics integrates the more engineering related subjects of geodesy with some of mechanical and electrical engineering as well as robotics, mechatronics and computer science in an interdisciplinary fashion for applications such as autonomous driving and other areas of mobile robotics. Finally, Remote sensing and GIS focusses on the acquisition and processing of geodata, mainly from space and on tackling scientific solving problems in applications such as environmental monitoring, climate change studies and sustainable development, the latter in cooperation with other geo-related disciplines. In all three specialisations, the first semester establishes a general knowledge base, the following two semesters allow for a specialisation according to the student’s interests, followed by one semester for the Master’s thesis.

Application to the M.Sc. programme is open to students from across the world with a first degree in surveying, geodesy, geoinformatics or related fields such as computer science, geography, earth science, civil engineering, or physics; furthermore, candidates must demonstrate that they have a sufficient knowledge of the English language. If the level of knowledge in geodesy and geoinformatics cannot be established from the submitted documents, video call interviews are being scheduled to assess the student’s ability to follow the M.Sc. courses. Students, who are judged to have the potential to successfully go through the programme, but lack some basic skills, can be admitted provisionally; in this case they have to pass up to three special courses within the first year to gain sufficient knowledge to follow the regular programme. These special courses are offered in each semester and deal with 3D image processing and computer programming, estimation theory and an introduction to physical geodesy and GNSS, respectively. Furthermore, depending on their B.Sc. degree, a slightly different set of modules is being offered to students with different background in order to best suit their needs.

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In more detail, the master programme consists of compulsory and elective modules. Six mandatory subjects, one each from Engineering Geodesy, Positioning and Navigation, Physical Geodesy, Photogrammetry and Remote Sensing, Cartography and Land Management, form the compulsory part and ensure that the study programme has the required breadth. In addition, a number of electives can be chosen, where a minimum of two subjects must come from both, engineering and physical geodesy on the one side, and photogrammetry/ remote sensing/cartography/land management on the other.
The programme is complimented by seminars, project work, an optional one week-long excursion and a block of studium generale, in which lectures from the whole university catalogue can be chosen to enlarge one’s intellectual knowledge. The last semester is devoted to the Master´s thesis, worth 25% of the whole programme, in which students must demonstrate that they are capable of solving a scientific problem in adequate depth and of describing the topic. Self-critical scientific thinking and a proper and justified evaluation of the obtained results are key to a good thesis.

Overarching ideas of the M.Sc. programme are to teach concepts, which remain valid for a longer period of time (these are typically the more theoretical ones), to point out similarities between seemingly disconnected subjects (to give an example, the “curvature” of a grey value function in image processing is of course identical to that of the geoid), to find a good balance between a common geodetic base and the individual preferences of students with respect to specialisations and electives, and to teach problem solving strategies as opposed to only having to learn by heart certain facts. The goal is that at the end of their studies students are equipped with a self-critical scientific mindset which lets them successfully approach new challenges on their own. While this may come at the cost of being immediately able to solve everyday practical problems, experience has shown that in the long-term achieving those goals prepares students much better to a successful career in geodesy and geoinformatics.

International exchange is possible through a number of ERASMUS contracts within Europe, e.g., with Newcastle University/UK, École Nationale de Sciences Géographiques (ENSG) in Paris/France, the Universitat Politècnica de València/Spain, Aalto University in Espoo/Finland, Istanbul Technical University/Turkey, and Budapest University of Technology and Economics/Hungary. Through personal contacts of the staff, students may also have the possibility to attend courses in universities outside Europe. Example destinations have previously included The Ohio State University in Columbus, OH, USA, the University of New Brunswick in Frederickton, the University of Calgary, both located in Canada, and the University of Melbourne, Australia, to name but a few examples. Most students stay for one semester; the foreign country and the foreign culture are an eye-opener, and students take significant profits from the time abroad.

European students can apply until January 15 for the following summer semester and until July 15 for the next winter semester. As non-European students typically need more time, e.g., to obtain a visa, the deadlines are 6 weeks earlier, i.e., on November 30 for next year’s summer and on May 31 for the winter (LUH_G&G_application, 2024).

4.3 Examples of schedules for the different specialisations

The following figures describe the course schedule for the individual specialisations. Figure 4 shows the one for Geomatics starting in winter semester. Besides the names of the individual lectures also the number of credit points according to the European Credit Transfer System (ECTS) is given, where one point is considered to be equivalent to 30 h or work throughout the semester. The subjects coloured in grey are the mandatory courses, two so called project seminars (one incl. a presentation seminar, one without) can be seen in light blue. In addition, there are seven modules to be chosen from a list of subjects in geodesy and geoinformatics, called mandatory electives and depicted in green in Figure 4. Subjects include

- Image analysis,
- Image sequence analysis,
- Radar remote sensing,
- Laser scanning,
- Spatial data science,
- SLAM and path finding,
- Machine Learning Models in Eng. Geodesy,
- Industrial surveying,
- Analysis of deformation measurements,
- HydroGeodesy and Geodynamics,
- Orbit calculation and relativistic modelling,
- GNSS receiver technology,
- Physical geodesy,
- Gravimetry

and others (see LUH_G&G_MSc, 2024 for details, incl. the syllabus of all subjects). A block containing the studium generale, in which subjects from the whole university catalogue can be chosen (shown in orange) and the master thesis (in dark blue) complete the curriculum.

Figure 5 shows the corresponding curriculum for the Navigation and Field Robotics specialisation, this time for students with a Bachelor in computer science and other non-G&G engineering fields. In this case, more mandatory subjects need to be taken in order to generate a solid base in geodesy; as a consequence, fewer mandatory electives are available. The mandatory electives, which can be chosen are similar to those in Geomatics.

Finally, Figure 6 depicts similar information for the Remote Sensing and GIS specialisation, again for students with a non-G&G Bachelor degree; the curriculum is particularly suited for students with a geosciences or geography background. For this specialisation the mandatory electives will include, among others

- Integrated Water Resources Management,
- Urban and Agricultural Hydrology,
- Meteorology and Climatology,
- Hyperspectral Remote Sensing,
- Electromagnetic Radiation,
- Ecosystem Services and Human-Env. Relations,
- Global change and Environmental Justice.

In this way, while all three specialisations have a common core, they allow the students to choose their individual programme along their background, interests and future career plans.

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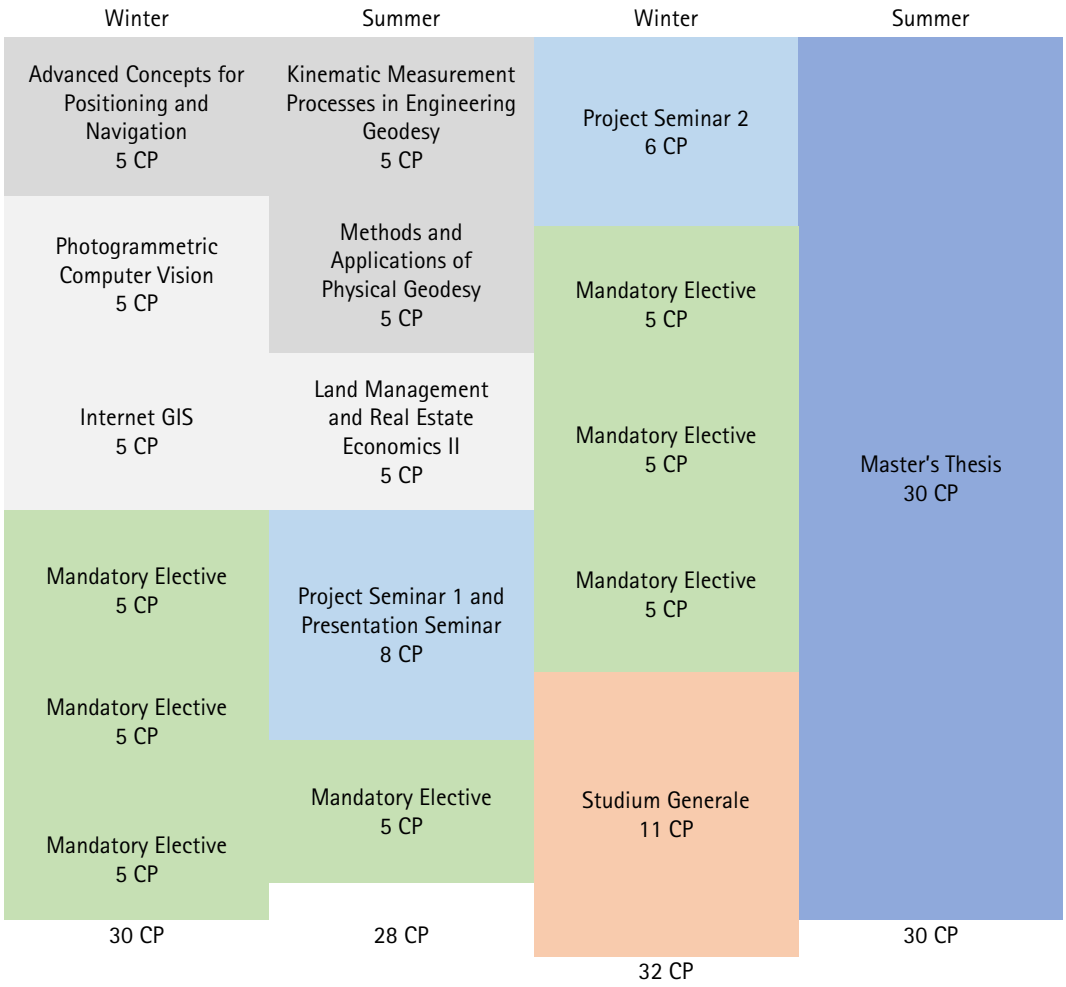

Figure 4: Course schedule of the Geomatics specialisation for a start in winter

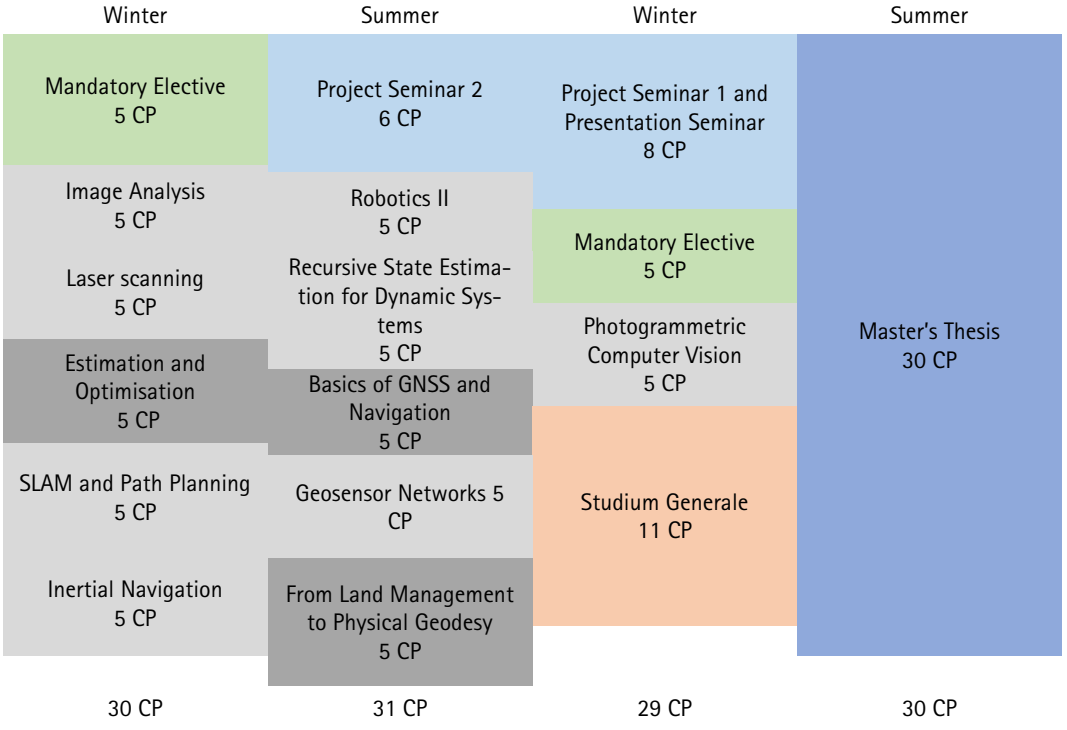

Figure 5: Schedule of the Navigation and Field Robotics specialisation for students with a non-G&G Bachelor degree, start in winter

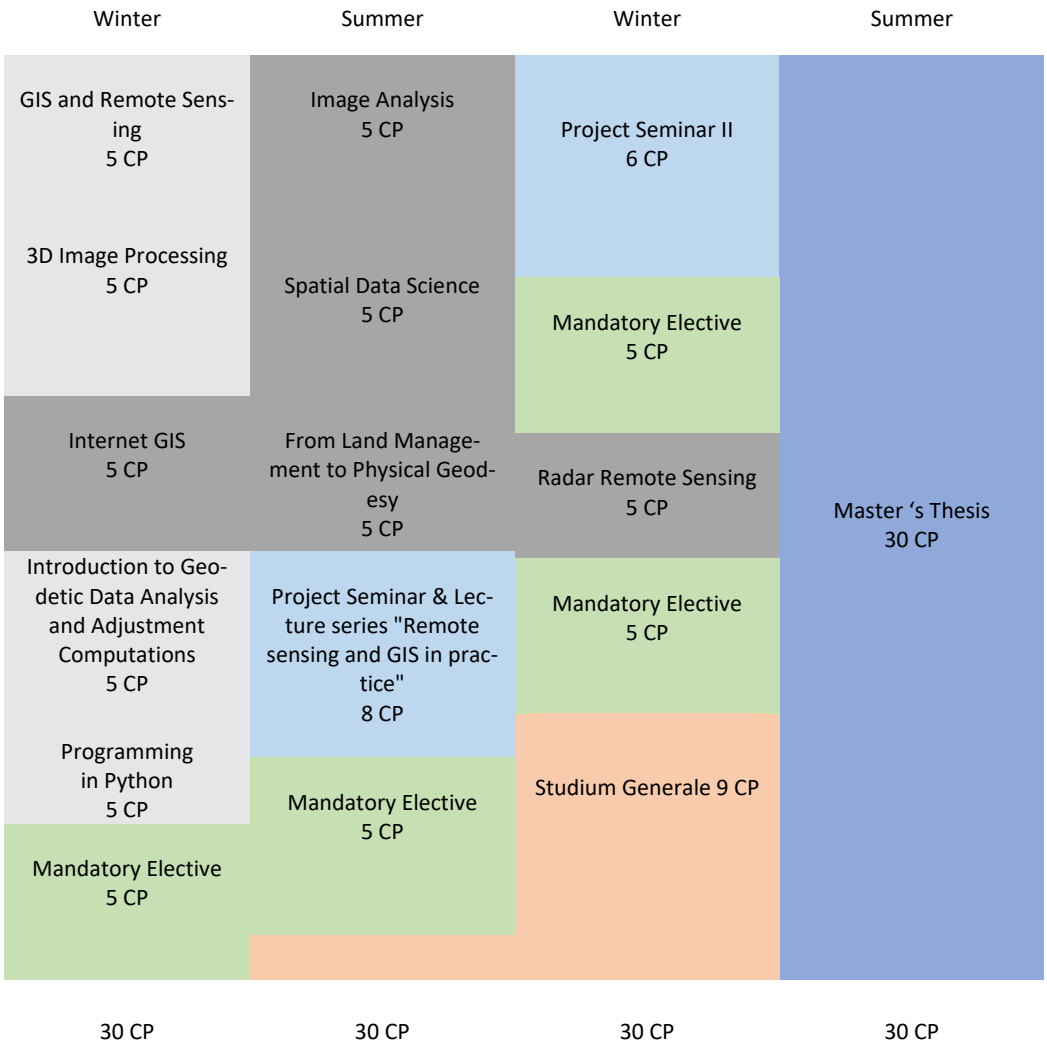

Figure 6: Schedule of the Remote Sensing and GIS specialisation for students with a non-G&G Bachelor degree, start in winter

5. Conclusions

Spatial data acquisition, management and analysis are key to meet many of today’s grand challenges incl. sustainable development, mobility, energy and global change. Geodesy and geoinformatics is the, not so well known but essential discipline which deals with spatial data and spatial data infrastructure. It is an exciting engineering discipline with links to mathematics and natural sciences as well as geo- and social sciences. Students have excellent career opportunities.

Germany is a country with a long and well-known tradition in engineering and in particular in geodesy and geoinformatics. Moreover, the country does not have tuition fees. Studying geodesy and geoinformatics at one of the German research universities, e.g., at Leibniz University Hannover, equips students with the necessary mindset and tools to make a difference in their personal life and in their local and national community.

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