Mobile Mapping and Navigation Systems – a new master's program in the field of geomatics launched in covid-19 pandemic time

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Keywords: mobile mapping, education, geomatics, GNSS, photogrammetry, cartography, lidar, blended learning

SUMMARY

Nowadays, technologies are characterised by solutions that increasingly support users leading to automation and autonomous work. More complex systems integrate technological solutions from various fields of science. It demands conducting interdisciplinary fields of study. The Faculty of Geodesy and Cartography of the Warsaw University of Technology has opened a new master's program, a unique course in Central and Eastern Europe. The specialisation of Mobile Mapping and Navigation Systems (MMNS) was launched in the studies of geodesy and cartography in October 2020 to meet modern technological trends and develop educational opportunities for international students in the best technical university in Poland. The study program has been created in cooperation with industry representatives and is tailored for modern technological needs to meet the expectation of the geomatics labour market. The student who is graduated from this program should know about designing mobile mapping platforms, especially how to select, calibrate, and integrate measuring sensors such as GNSS receivers, inertial measurement units, LIDAR, photogrammetric cameras etc.

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1. INTRODUCTION

In October 2020, the Faculty of Geodesy and Cartography of the Warsaw University of Technology opened a new international master's degree study in the field of geodesy and cartography with a specialisation in Mobile Mapping and Navigation Systems (MMNS). The inauguration of the first study cycle was accompanied by the 100th anniversary of the faculty's founding. Taking advantage of the long-term experience of the faculty's staff in education in geodesy, a new program for the entire cycle of master's studies has been successfully prepared, considering modern technological trends and the expectation of the labour market. The program has been elaborated within the task: "Internationalization of studies at the Faculty of Geodesy and Cartography" of the Warsaw University of Technology project NERW (Science - Education - Development - Cooperation) co-financed by the European Union. The main goal of the project was to improve the quality of functioning of the Warsaw University of Technology, both in education and management, and to adapt the University's teaching offer to the needs of the labour market through the implementation of a comprehensive program of activities for the performance of student-oriented education.

By analysing the market needs and the development of technology, an increase in the demand dealing with the following scope can be noticed:

- processing and analysis of geospatial data,
- creating models and 3D products from spatial data,
- technologies of positioning, operation and orientation of mobile measurement platforms, such as unmanned aerial vehicles (UAV), car-based platforms, autonomous vehicles,
- developing localisation and navigation applications,
- creating systems for crisis management and Smart City,
- technologies of intelligent transport.

Currently, employees in the geoinformation market should also be characterised by skills such as:

- design of geoinformatics applications, including spatial information systems, geoportals, mapping systems, location and navigation applications,
- design and preparation of comprehensive navigation and mobile cartography applications,
- development of applications for navigation and orientation of mobile measurement platforms, such as UAVs or autonomous cars.

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An attractive scope and formula for students from the perspective of modern technologies and system solutions should characterise this new study program.

Fulfilling the main goals of the NERW project, the MMNS program has been created in cooperation with industry representatives. It is tailored for modern technological needs to meet the expectation of the geomatics labour market. The course content involves the nowadays technologies characterised by solutions that increasingly support users leading to automation and autonomous work. It demands the implementation of kinematic measurement systems and the methods to elaborate the geospatial data in a kinematic mode. Furthermore, more complex systems require integrating technological solutions from various fields of science to accomplish that the representatives of the mechatronics and transport fields of study were involved in preparing the course content and conducting the lectures.

2. ANALYSIS OF THE EDUCATIONAL OPPORTUNITIES

When planning the studies, the availability of English thought second-cycle study programs in the field of geodesy, geomatics and geoinformatics in Poland, Europe and Canada were analysed. At European and Canadian universities (e.g. Lund, Gavle, Aalto, Newcastle, Calgary), the master's degree programme typically lasts two years (four semesters) and covers a total of 120 ECTS.

For example, at Lund University (Sweden), the Master´s programme in Geomatics aims to provide courses in a wide range of geomatics, including geographic information systems (GIS), geodesy, remote sensing and computer science. The programme consists of three parts. The first part provides theoretical courses in e.g. computer science and statistics. The second part contains several courses in geographic information technology regarding collecting data – mainly remote sensing and geodesy, storage of data – e.g. spatial database technology, treatment of data – fundamental algorithms in geographical analysis, distribution of data – e.g. standardised web services, and visualisation – e.g. cartographic rules for screen display. The third and last part treats applications mainly focusing on environmental, physical and urban planning.

Another example is Graz TU (Germany), which conducts studies in the field of geomatics in 3 specialities: Geoinformation / Remote Sensing, Navigation / Satellite Geodesy and Engineering Geodesy / Cadastre. Students can choose one of the three available specialisations that can be combined and supplemented with courses from other fields of study. The studies are conducted in German and therefore targeted German-speaking audiences.

At Schulich University in Calgary (Canada), the master's programme in geoinformatics is organised by the School of Engineering. It specialises in the acquisition, analysis and visualisation of geospatial data. It integrates engineering applications within environmental sciences. The learning outcomes include technical, mathematical, computational and visual knowledge and skills in managing spatial phenomena. The programme offers students the possibility to use state-of-the-art geoinformation technologies in developing new computational methods and applications.

Also, some Polish universities offering studies in geomatics were analysed. Table 1 shows the leading Polish universities comparing chosen organisational aspects.

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Table 1. List of Polish Universities offering full-time English-thought master's programs (source: https://study.gov.pl/studyfinder)

University	City/ Country	Field of study, specialization	Length of study/ ECTS / hours	Tuition fee
Warsaw University of Technology	Warsaw/ Poland	Geodesy and cartography / Mobile Mapping and Navigation Systems	3 semesters / 90 ECTS / 1200h	1500 EUR per sem.
University of Warmia and Mazury in Olsztyn	Olsztyn/ Poland	Geodesy and cartography	3 semesters / 90 ECTS / 1100 h	4800 PLN per sem (about 1000 euro)
Wrocław University of Science and Technology	Wroclaw/ Poland	Geomatics	4 semesters / 120 ECTS	2000 euros per sem
Poznań University of Life Sciences	Poznań / Poland	Geoinformation Science, Earth Observation and Spatial Management	4 semesters / 120 ECTS / 800 h	1000 EUR per sem.

The programs of the studies at the universities in Poland were also compared. While the first general semester does not differ much, the second and the third semesters are already significantly different from the general education trend focusing on mobile mapping and navigation systems.

3. MOBILE MAPPING AND NAVIGATION SYSTEMS

3.1. Programme and course content

The MMNS program targets holders of a bachelor with a qualification in application areas of geodesy, geomatic, geoinformatics, geoinformation, geoscience, cartography and geographic information systems. We also particularly welcome computer scientists with a keen interest in GIScience. It is required to have acquired at least basic skills in computer science and geoinformatics before starting the master's program. Master of Science will award graduates who will accomplish the entire cycle of study in Engineering degree course (abbreviated MScE or M.Sc.Eng.), which is a degree usually awarded by the technical university in the engineering field of science; it is considered as equivalent to a standard Master of Science degree. The regular program of the MMNS (tab. 2) lengths three semesters and requires the students to collect 90 credit points corresponding to the European Credit Transfer and Accumulation System (ECTS).

Table. 2. Detailed program of Mobile Mapping and Navigation field of study at Faculty of Geodesy and Cartography of Warsaw University of Technology

Sem. 1

Course title	ECTS	Lectures	Tutorials	Project	Sum
Basics of international economic law and intellectual property law	1	15			15
Modern photogrammetry	3	30		30	60
A programming language with numerical methods	2			30	30
Mobile and Navigational Cartography	3	15		30	45
Standards for geodata	1	15		15	30

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Course title	ECTS	Lectures	Tutorials	Project	Sum
Reference systems for navigation	2	15		15	30
Satellite navigation systems	3	15		30	45
Selected sections of physical geodesy and geodynamics	2			15	15
Selected problems of stochastic data analysis	4	15	30		45
Geophysics	2	15	15		30
Mathematics	3		30		30
Image recognition and deep machine learning	4	30	0	30	60
Sum of credit points and hours per semester:	30	165	75	195	435

Sem. 2

Course title	ECTS	Lectures	Tutorials	Project	Sum
Geodetic and Cartographic Documentation	2	15			15
Principles of transport economics	2	30			30
English for Geomatics	1		30		30
Facultative course 1- Modern Measuring Instruments	2	15		15	30
Facultative course 2 - Application of aerial and satellite photogrammetry	2	30		15	30
Facultative course 1- Building Information Modelling	2	15		15	30
Facultative course 1- Surveying services of investment	2	15		15	30
Facultative course 1 - Robustness of observation systems to gross errors	2	15		15	30
Facultative course 2 - Augmented Reality	2	15		15	30
Facultative course 2 - Indoor navigation	2	15		15	30
Algorithmics of navigation applications	3	15		30	45
Simultaneous localisation and mapping (SLAM)	3	15		15	30
Spatial analysis	2			30	30
Mobile mapping technologies	4	15		30	45
3D city modelling	2	15		15	30
Integrated navigation systems	4	15		30	45
Computer Vision and 3D data processing	3	15		15	30
Sum of credit points and hours per semester:	30	255	30	270	540

Sem. 3

Course title	ECTS	Lectures	Tutorials	Project	Sum
Facultative course 3 - Selected procedures of land management	2	30			30
Facultative course 3 - Finance of property markets	2	30			30
Facultative course 3 - Principles of property market economics	2	30			30
Facultative course 3 - Contemporary challenges in cities' development plan.	2	30			30
Spatial Data Mining and Big Data	3	15		15	30
Intelligent Transportation Systems and Autonomous Cars	1	15			15
Urban solutions for autonomous vehicles	1	15			15
Practices in fields	2		15		15
Diploma seminar	1		30		30
Diploma thesis	20				
Sum of credit points and hours per semester:	30	165	45	15	225

3.2 Profile of graduated student

The specialisation graduate is characterised by knowledge in the field of broadly understood geoinformation sciences and issues related to indoor and outdoor navigation. In particular, the graduate has knowledge and skills in spatial data acquisition technologies, processing techniques, model building, visualisation of spatial data, and services supporting decision-making in geoinformation and navigation. The graduates also know positioning methods using satellite systems, including integrated systems (GNSS/INS), hybrid technologies (Assisted-GNSS) and technologies used for navigation. They can process various photogrammetric and remote sensing data obtained by manned and unmanned measurement platforms from the air and ground level, including unmanned aerial vehicles (UAV), mobile measurement systems (MMS), and autonomous vehicles. The graduate is also prepared to work in companies and institutions developing and implementing various geoinformatics products, including 3D products, digital maps, mobile cartography products, applications for platforms equipped with photogrammetric and remote sensing sensors (multi- and hyperspectral cameras, laser) and positioning and orientation sensors, applications for acquiring, visualising and processing spatial data, as well. Some photos presented in figures 1-3 show students' works or students during classes following such steps as developing and programming, testing, measuring, and visualising.

Figure 1. Students work: programming, developing devices and testing

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Figure 2. Students work on the measurement using terrestrial laser scanner and mobile scanning backpack
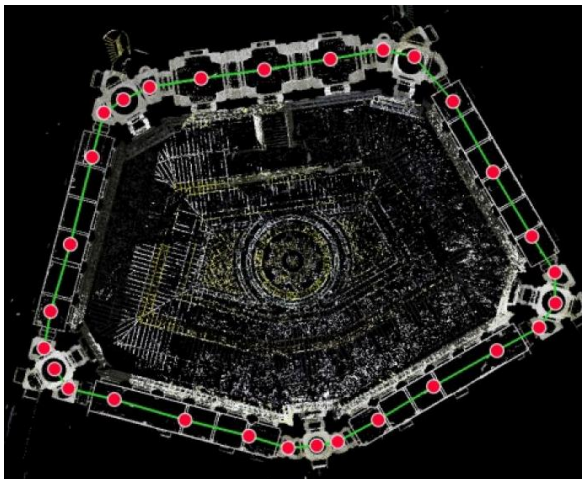

Figure 3. Students' work: the visualisations of the acquired point cloud from laser scanning (TLS and MLS).

3.3 Industry collaboration & job opportunities

The faculty industry contacts lead to highly sought-after employment and cutting-edge research opportunities with real-world applications. To stress the connection with the industry and practical character of the MMNS program, the course is conducted in cooperation with branded companies that are the faculty's educational and scientific partners. Among many others, the

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Warsaw, Poland, 11–15 September 2022

three companies: TomTom, Smart Factor, and Hexagon, are strategic partners in realising the MMNS program. Cooperation relies on the continuous exchange of experience in modern technological solutions and their applications. Together with our partners, we can offer the students practical classes, field exercises and thesis topics related to the real problems and needs of the industry market.

Figure 4. Practical classes on mobile mapping systems conducted in cooperation with our industrial partners (courtesy: from TomTom, Smart Factor)

Nowadays, technologies are characterised by solutions that increasingly support users leading to automation and autonomous work. More complex systems integrate technological solutions from various fields of science. Due to that, it becomes crucial to understand the basic principles of work of an individual system component and its possibilities of integration to achieve an optimal operation of the final applications. Thus, the recent job offers require new specialists who can design and configure systems utilising interdisciplinary technology. Such a specialist must be able to apply and use multiple sensors, dedicated software, Big Data or neural network analysis.

The MMNS degree program covers such topics to prepare graduates to:

- design mobile measurement platforms (UAV, self-driving cars, MMS/MLS). Students work with data from aerial and terrestrial mobile platforms equipped with optical (images), lidar (laser scanner), and GNSS (GPS) sensors providing geospatial information. Students learn the basics of sensors' location in a platform and the relation between them.
- develop precise positioning systems (GNSS, GNSS/INS). Students learn how to write an application for accurate positioning determination (e.g. DGNSS, RTK) based on data from the GNSS system, e.g. GPS. The student will be able to create an application integrating GNSS data with INS data to determine the accurate and reliable position required by the navigation systems in urban canyon environments.
- develop an application for attitude determination and control. Based on GNSS and INS data, students learn how to determine and control a moving vehicle's attitude (yaw,

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Warsaw, Poland, 11–15 September 2022

pitch, roll). These parameters are needed to navigate moving vehicles (UAV); moreover, they are required for the orientation of the other measurement sensors (e.g. camera, LIDAR) concerning the platform.

− collect, process and analyse geospatial data from mobile mapping platforms. Students participate in data collection projects with mobile mapping systems equipped with image-based and lidar-based sensors to acquire geospatial data during platform rides. This data can be applied to the inventory of roads and infrastructure located on it.

− select appropriate techniques for acquiring spatial data (photogrammetry, remote sensing, computer vision). Students participate in projects related to data acquisition with UAV systems and other photogrammetric and remote sensing techniques. Low-altitude aerial images are the popular data source for many applications in engineering, natural and human sciences. The processing of images is a popular issue in computer vision. Students learn it and get knowledge about selecting the proper technique in the best approach to receive the appropriate solution.

− develop advanced geovisualisation of spatial data for navigation or other systems. Students practice cartographic modelling and visualisation. Students process point clouds from laser scanning and other datasets (vector and raster) to 2D and 3D maps (indoor and outdoor) used in mobile apps.

4. BLENDED LEARNING AND STUDY ORGANIZATION DURING THE PANDEMIC

4.1. Pandemics influence on studies organisation

One of the priorities of the Faculty of Geodesy and Cartography WUT is to internationalise the educational offer. After years of preparation, these efforts were carried out in 2019, when work began on the new English-language offer of the faculty. The first cycle of MMNS studies began in October 2020. Unfortunately, due to the COVID-19 pandemic situation, the mode of the study has been reorganised. All lectures and classes were provided remotely instead of regular on-campus courses during the first semester. During the second semester, a lower risk of the pandemic situation allowed for scheduled blended learning. That approach combines online lectures and opportunities for interaction online with traditional onsite classroom methods. The theoretical lectures were taught online, and practical classes were taught on campus in the University laboratories. Due to the practical character of the studies, it was crucial to perform some courses with traditional stationary typical classroom methods. On the other hand, the online mode allowed lecturers from other countries and universities to be invited. Since the MMNS studies are co-financed by the European Union, we were able to ask many outstanding guest lecturers from European universities and scientific institutions (i.e. Vienna University of Technology, University of Zurich, Politecnico di Milano, Joint Research Center (JRC) European Commission, University of Messina etc.). The third semester of the first edition and the first semester of the second edition of MMNS were started with blended learning, but during the semester, once again, classes were organised in a totally remote way from December 2021 to February 2022. These changes in mode of educational mode are shown in Figure 5.

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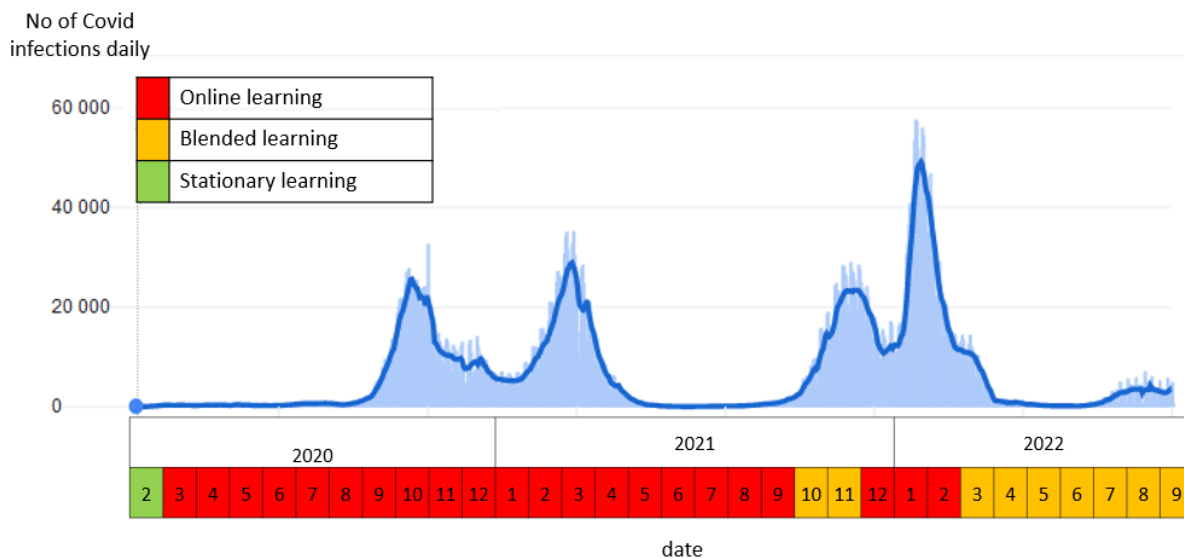Warsaw, Poland, 11–15 September 2022

Figure 5. Number of daily COVID infections (picks) and their 7-day average number (line) showing the COVID situation in Poland with the form of education in WUT in months of pandemics (February 2020 – September 2022)

Summarising the COVID-19 pandemic period, which forced online or blending classes to be conducted, this time could have been better for opening a new course in Geomatics. However, this decision must have been made due to the unknown pandemic situation and its duration. A flexible organisation referred to the form of classes that encouraged people to attend this course.

4.2.Admissions

Thanks to the MMN specialisation, the share of foreign students in Faculty of Geodesy and Cartography WUT is 5% of the total number of faculty students, 7% of the field of geodesy and cartography, but as much as nearly 30% of geodesy and second cycle cartography. This is a level unheard of state universities in Poland, especially in the field of geodesy and cartography, because other centres do not offer systematically opened foreign-language specializations and in the field of geodesy and cartography (geomatics). The applicant students come from various countries like Nigeria, India, Turkey, Indonesia, Rwanda, Kenya, Ethiopia, Belize, Lebanon, Tunisia, and Turkmenistan, as shown on the map in Figure 6. It should be noted that these countries are mainly developing countries. Despite a much lower tuition fee for Polish and EU students (1100 zlotys and 1500 zlotys starting from the 3rd MMNS edition) than for non-EU people (1000 euros and 1500 euros starting from the 3rd MMNS edition), candidates from Europe have yet to be noticed in the last three calls. Nigeria, India, Turkey and Pakistan are at the forefront of recruitment.

The admission system for WUT allows candidates to choose 3 field of education, taking into account whether a given applicant has shown interest in a given direction. Statistical data from 3 admissions are shown in Table 3, referring to applicants' nationality. However, the great interest of several dozens looks twice worse when we analyse the number of candidates who choose MMNS from the first choice. Half of the qualified people pay tuition fees, and even

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Volunteering for the future - Geospatial excellence for a better living
Warsaw, Poland, 11–15 September 2022

fewer go through the visa procedure. Finally, in the last three years, gathering groups within the limit of 16 people as possible should be considered satisfactory during difficult times for human mobility.
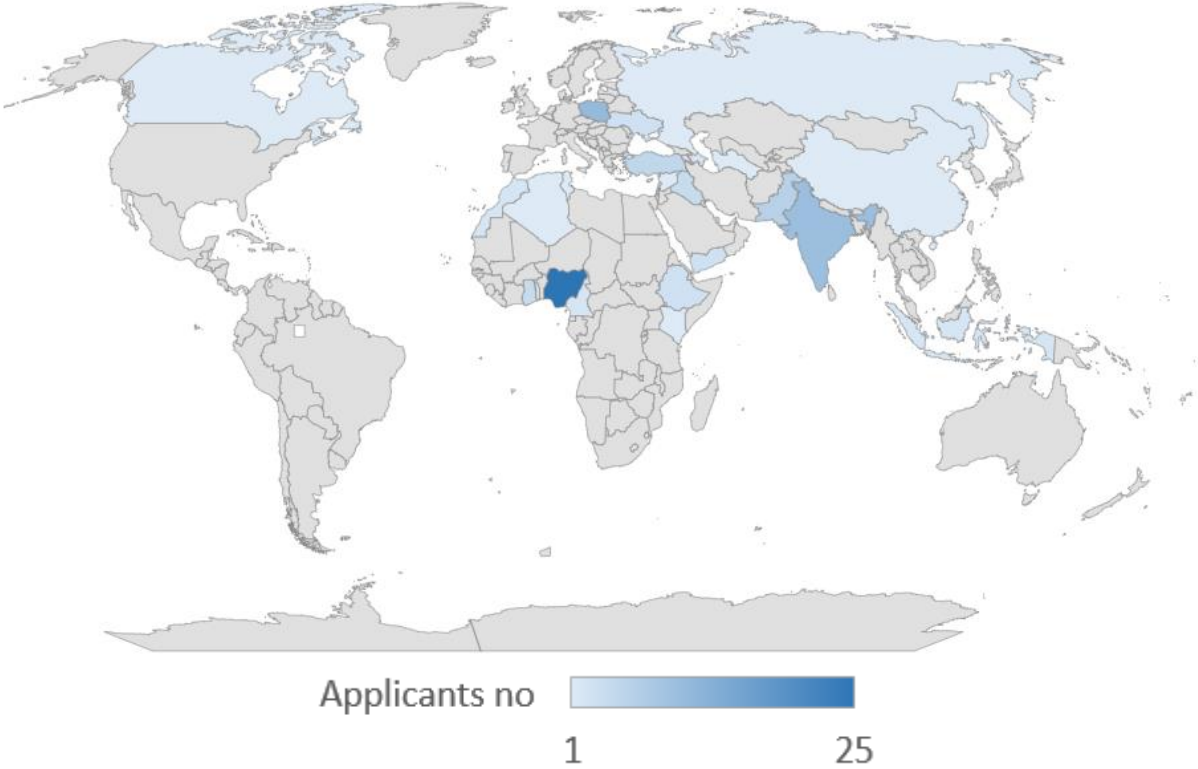

Figure 6. Countries of origin for applicants to MMNS in three study editions

Table 3. Statistics for MMNS course admission in editions 2020-2022

Statistics	1st edition 2020 admission	2nd edition 2021 admission	3rd edition 2022 admission
MMNS in the 1st choice	10	59	31
MMNS in all 3 students' choices	11	100	52
Students accepted for studies	6	30	15
Students started education	6	20	9
Students passed the 1st semester	4	16	N/A
Students passed all classes	4	N/A	N/A
Students graduated	0	N/A	N/A

4.3. Scholarships opportunities

Poland offers scholarships to students through the government, various foundations, and universities. Many of the scholarships are provided by Polish National Agency for Academic

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Volunteering for the future - Geospatial excellence for a better living
Warsaw, Poland, 11–15 September 2022

Exchange (NAWA) which coordinates scholarship programs under terms outlined in agreements, with the collaboration of Polish diplomatic missions and institutes, which will publish the offer for students on their websites. The grant amount depends on the type of scholarship program. The most recent offers of the scholarship programs for foreign students:

- The gen. Anders Programme
- The Banach Scholarship Programme
- Poland My First Choice Programme
- Exchange Programme for students and scientists as part of bilateral cooperation
- Polish Language Programme - POLONISTA
- NAWA Summer Courses

Furthermore, WUT has contacts with many educational and research institutions, and it allows to go abroad, joint projects such as Erasmus+, Student Exchange Programmes, Double Degree Master Programmes, Polish and American Fullbright Commission, DAAD, CEEPUS, and Summer Schools. Students can participate in various job placements and carry out their diplomas in the branches of renowned companies worldwide.

5. FUTURE PLANS

In the coming years, further development of the specialisation is planned. The intention is to expand cooperation with companies and other Universities. The new research infrastructure created at WUT will soon be made available to students. By 2023, students will be able to use laboratories built within the new Center for Scientific Geospatial Analysis in their research work. These are both stationary and virtual laboratories (IT Cloud Platform). Within the former group, students will be able to use the following:

1) Terrestrial Laser Scanning and Photogrammetric Calibration Laboratory with UAV test fields;
2) The surveying reference outdoor baseline for research and calibration of measurement instruments;
3) Navigation Application Testing Laboratory with indoor navigation/localisation test fields;
4) GNSS Receiver Calibration Laboratory;

Very modern equipment is available in these laboratories, including a GNSS simulator (GSS9000 Series GNSS Simulator), industrial laser tracker for highly accurate 3D measurements (made by API), BOSCH-REXROTH Linear Rail Systems for linear and non-linear movement of objects on the measurement base, and many Virtual Reality, Augmented Reality/Mixed Reality solutions.

As for the virtual laboratory, students will be able to conduct research using geo-cyberinfrastructure of geospatial data, including using high computational power, analysing rich geospatial data resources, and using AI techniques in distributed infrastructure in their work. Students will be able to use the big data environment in their work.

At the end of 2022, new test fields will also be available: a field for UAV testing and a field for testing indoor navigation systems. In the following years, WUT plans to build an outdoor test

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Volunteering for the future - Geospatial excellence for a better living
Warsaw, Poland, 11–15 September 2022

field for autonomous vehicles (dedicated to testing the quality of data collection systems and the quality positioning systems)

The priority of the faculty in the situation of demographic crisis is English-language studies. Having a course taught in English has significantly developed the teaching staff. Still, it has also helped to increase the internationalisation of the faculty through a more significant number of students coming for student exchange, as well as the emergence of non-Polish researchers who have where and with whom to conduct classes in a language other than Polish. The English-taught offer led to the signing of a double diploma agreement with Universitat Politècnica de València. Plans for the development and popularisation of the course are significantly related to the countries of Africa and Asia, for which Poland is an attractive country, which, however, allows you to maintain itself at a sufficient level due to low prices and costs of living, which is much more difficult in Western European countries.

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Joanna Pluto-Kossakowska, Kinga Węzka, Dariusz Gotlib and Krzysztof Bakuła (Poland)

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Warsaw, Poland, 11–15 September 2022

BIOGRAPHICAL NOTES

Joanna Pluto-Kossakowska

Doctor of technical sciences in the field of Geodesy and Cartography, Ph.D. in Remote Sensing and soil databases (2003). She is working at WUT to contribute to teaching and research projects related to Remote Sensing and GIS. Between 2005-2009 she was employed at Joint Research Centre as Scientific Officer. She was responsible for scientific and technical projects on the development of control methods in agriculture using remote sensing techniques, radar and optical satellite image processing, and interpretation methods. She has deep knowledge of image processing methods and extensive experience in remote sensing and GIS software tools. She was involved in more than 20 research projects related to Remote Sensing and GIS applications, spatial analysis, and modelling.

Kinga Węzka

Master of Science in Engineering degree in the field of Geodesy and Cartography with a specialisation in Geodesy and Satellite Navigation received at the Warsaw University of Technology. Since 2018, she has been working as a research and teaching assistant at the Warsaw University of Technology. Her scientific activities focus on GNSS-based precise positioning, integrated GNSS/INS navigation systems and space weather monitoring from GNSS signals. Between 2011-2018 she was employed as an early-stage researcher at the Technische Universität in Berlin at the Institute of Geodesy and Geoinformation Science. Between 2011-2014 she was a fellow of Marie Skłodowska-Curie Actions in the European project TRANSMIT. She was involved in more than ten research projects on GNSS-based precise positioning.

Krzysztof Bakuła

Assistant professor in the Department of Photogrammetry, Remote Sensing and Spatial Information Systems and Vice-dean for students' affairs and international cooperation (2020-2024) responsible for education in English and students' mobility. Scientists interested in analysing and applying airborne and satellite, multi-sourced data (photogrammetric and LIDAR). Manager of projects using UAV datasets in civil engineering and forestry applications, including IT solutions in artificial intelligence. Lecturer conducting lectures and exercises in geodesy and cartography, spatial planning, and geoinformatics. He is involved in the works of ISPRS, EuroSDR, the Polish Society for Photogrammetry and Remote Sensing and the Association of Polish Surveyors.

Dariusz Gotlib

Assoc. professor at the Warsaw University of Technology employed at the Faculty of Geodesy and Cartography since 2001. Vice-Dean for Development and Cooperation with the Economy (2020-2024). Cartographer-geoinformatics researcher. Originator and manager of the project of creating a Center for Scientific Geospatial and Satellite Analyses at the Warsaw University of Technology. His research and teaching interests include issues in geoinformation, in particular: geoinformatics, mobile and navigation cartography, LBS (Location-Based Services), spatial data infrastructure, and GIS.

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