Studying Acoustics at NTNU

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While it is a well established discipline in academia with a broad range of applications, acoustics is usually not big enough a subject to exist at the department level of a university. Acoustics easily suffers from a lack of visibility in higher education, especially for young students at the start of university studies. Moreover, when the organization of the university is application-oriented, the transverse nature of acoustics makes it difficult to find a suitable place for the discipline. This communication deals with the particular case of NTNU which has a long established activity in acoustics. The current situation of a specialization in acoustics under the umbrella of a master programme in electronics is described. The students in acoustics at NTNU can benefit from a variety of courses offered and have access to topics that are uncommon elsewhere in Scandinavia, like musical acoustics, bioacoustics, underwater acoustics and geoacoustics. Alternative tracks are also described for the students with backgrounds in physics or civil engineering. Potential improvements to the current situation are discussed.

1 Introduction

NTNU has been offering education in acoustics for more than 50 years. Although the number of acoustics courses proposed by NTNU is large enough to accommodate for different interests in the discipline, and although the learning environment offers many opportunities, the number of students taking their master's thesis in acoustics has been relatively low in the past years. This is at odds with the sustained demand for acousticians from the job market. This paradox may be related to the transverse nature of acoustics and deserves further analysis

This paper reviews the current situation of education in acoustics at NTNU. It is organized as follows. Section 2 returns to the origins of education in acoustics at NTNU. Section 3 considers the number of students who took an education in acoustics in the past 20 years. Section 4 reviews the portfolio of courses in acoustics at NTNU. Section 5 outlines the experimental facilities used in teaching and student projects. Section 6 illustrates how students can take courses in acoustics, depending on their study programme. Section 7 reviews the challenges of teaching acoustics at NTNU. Section 8 brings some conclusions and perpectives.

2 A bit of history of acoustics at NTNU

An acoustics laboratory was built in 1964 in a new extension to the electrotechnical engineering building and King Olav V was visiting for an official opening in 1965. The laboratory has a reverberation room with a connected room for measurements of sound transmission of doors, windows and small building elements. There is also a separate sound transmission laboratory for walls (horizontal pair of rooms) and floors (vertical pair of rooms). A few years earlier, an anechoic room had been built in the existing building, and the anechoic room was a bit special since it had mineral wool wedges that were covered with graphite powder in order to function as an antenna lab as well. This functionality was rarely used since a separate antenna lab was built later.

3 How many students? Past and present

Over the last 20 years, an average of 12 master students have taken acoustics courses in addition to completing a master thesis in the acoustics group, even though the number has been clearly less over the last 5 years, see Figure 1. More students have taken one or a few courses. Of these master students, more than 90% are from the electronics program, and the others from physics or civil engineering. For many years, the acoustics specialization suffered from a slowly decreasing number of students that selected, and stayed, in the Electronics program. A major change of the Electronics programme in 2015 has turned the negative trend so now, larger numbers of students are attracted to the "Electronic Systems Design" (ELSYS) programme. This is expected to lead to an increase in number of acoustics students in the coming years.

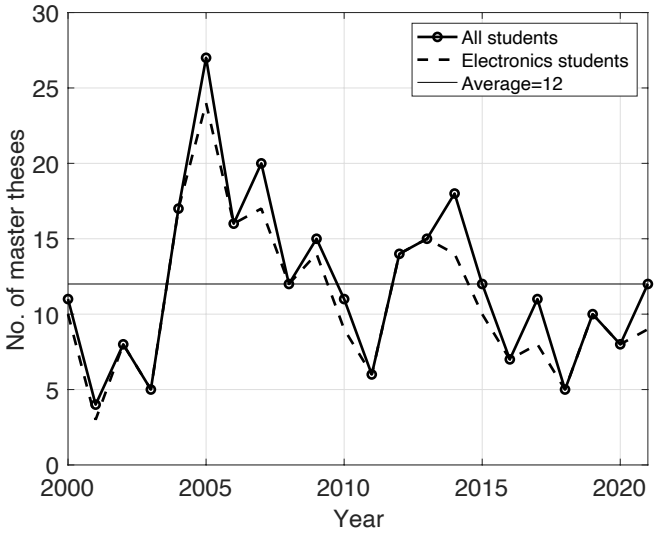

Figure 1 Number of students finishing with a Master thesis in acoustics at NTNU, 2000-2021.

4 A wide portfolio of courses

At NTNU, the standard size of courses is 7.5 ECTS. Unless otherwise specified the 23 courses discussed below fall into this format.

4.1 Bachelor level

While this happens to exist in other countries, to our knowledge there is no such thing as a bachelor level programme in acoustics in Norway. The Acoustics group does offer a course entitled *Music and perception* (TT2010) to students in a bachelor programme called Music Technology (BMUST). Among other more music-related aspects, Music and perception provides a minimal background in wave phenomena, room acoustics, hearing and psychoacoustics. Bachelor students in audiology have also some lectures about basic acoustics, hearing and psychoacoustics, and room acoustics, where the Acoustics group is involved on a less regular basis. Some acoustics content is included in other courses at NTNU such as *Wave propagation* (TFE4130), *Sensors and instrumentation* (TTT4280), and *Building Physics, basic course* (TBA4160).

4.2 Master level

Most of the courses under the responsibility of the Acoustics group are offered at the master level as part of the 5-year Norwegian *siv. ing.* program MTELSYS "Electronic Systems Design and Innovation" or the 2-year international master MSELSYS "Electronic Systems Design".

They include 2 introductory courses, namely *Technical Acoustics* (TTT4180) and *Marine Acoustics* (TTT4175). TTT4180 gives more emphasis on the basic equations of motion for various canonical mechanical systems and opens to the use of acoustics in building, transportation and civil engineering. TTT4175 discusses sound radiation and propagation phenomena underwater. Ray tracing and normal modes are presented, as well as various aspects of sonar systems for

remote sensing. The two courses include practical work like environmental sound recordings, simulation tasks relating to sound synthesis or propagation.

Acoustical measurement techniques (TTT4250) offers a more hands-on approach to acoustics. The course is based on labs performed in groups of 2 or 3 but with individual delivery of reports. Lab 1 is about sound power measurement with the use of pressure and sound intensity techniques; lab 2 consists of the measurement of the directivity of an underwater transducer; lab 3 deals with hearing thresholds and the efficiency of hearing protectors; lab 4 introduces the measurement of sound insulation; lab 5 is about the impedance of absorbing materials assessed in the standing wave tube and in free field. Each lab is introduced by a short lecture that gives the necessary theory.

Music Acoustics and Technology (TTT4197) considers acoustics in the context of music. It discusses the acoustics of musical instruments, but also hearing and perception.

Audio Technology (TTT4170) focuses on various transduction mechanisms, both for radiation and reception of sound. Furthermore, microphone array signal processing is covered, and sound reproduction techniques such as 3D audio, and auralization.

Besides attending lectures ELSYS students work on projects. During the fall of the 5th year the students take a specialization project worth either 7.5 or 15 ECTS. This can be seen a pre-master's thesis project where each student works on a specific topic under the supervision of a professor. The master's thesis, worth 30 ECTS, takes place during the last semester that is dedicated to the thesis. The allotted time for the thesis is relatively short in comparison to some other programmes, but there is always the possibility to work on the same topic during the specialization project and the master's thesis.

In the ELSYS framework, the specialization project goes hand in hand with advanced courses. Each advanced course is worth 3.75 ECTS. Every student must take two such courses among various possibilities. The supervisor of the specialization project recommends the most relevant courses in relation to the subject chosen by the student. The advanced courses offered by the Acoustics group feature *Acoustic remote sensing* (TTT03), *Numerical methods in acoustics – selected topics* (TTT12), *Environmental acoustics* (TTT17), *Marine acoustics – selected topics* (TTT19), *Bioacoustics* (TTT20), *Room acoustics* (TTT22). For instance, TTT12 introduces the finite differences and the finite elements methods, in addition to geometrical acoustics and ray-tracing; TTT17 discusses the key aspects of noise emission from transportation, industry, wind energy and noise propagation in the environment, but also the impacts of noise on health.

Since Fall 2020 a new course called *Acoustics of the built environment* (TTT4285) is offered. It combines the content of TTT17 with room acoustics. It offers a practice-oriented course that is close to the needs of a future acoustic consultant in the building sector. The intention is to provide the necessary background for those who will do environmental noise impact studies in relation to urban or infrastructure development, or who will design the acoustics of indoor spaces. For ELSYS students TTT4285 can serve as a substitute for the combination of two advanced courses, but TTT4285 looks particularly relevant for students from other faculties.

From Fall 2021, TTT4290 *Bioacoustics for biodiversity* will be offered to non-ELSYS students. It is a 7.5 ECTS variant of TTT20. Not all study programmes allow to choose smaller courses. The two courses share the same lectures but field works counts for 50 % of the final grade in TTT4290. For terrestreial and undewater environnements, TTT4290 covers sound production and reception in animals, sound propagation in the wild. The course considers also the impacts of noise from man-made activities and the possible mitigation measures. Through field work the students become more familiar with bioacoustics data collection and post-processing.

At NTNU, Experts in team is a 4th year mandatory course aiming at developing transdisciplinary teamwork skills. Students from all faculties join a thematic "village" to work in groups of 4-6. Each group is expected to define a project and to work on it during the spring semester. The Acoustics group is in charge of the Norwegian-speaking village entitled "*Lyd i hverdagen*" (TTT4850) that invites to consider the acoustic dimension of our daily life, like sound levels at concerts, urban noise or the impact of music on learning. In this context the students get more familiar with calibrated audio recording or playback, the use of a sound level meter or the design and performance of listening tests.

In addition to what is proposed by the Acoustics group, other acoustics-related courses are offered at NTNU, like *Building Acoustics* (TBA4167) that focuses on airborne and impact sound insulation, and noise from building equipments; *Physics and Geophysics* (TPG4100) that introduces the theory of elasticity and waves in solids ; *Medical imaging systems* (MEDT4160) discusses the theory and the application of ultrasound in living tissues; *Machine Learning and Speech Technology* (TTT4185) can also be relevant in a specialization in acoustics.

To the students that follow the master programme in Music Techology (MMUST), the Acoustics Group teaches *Audio Technology and Room Acoustics* (TT3010).

4.3 PhD level

Until very recently the Acoustics group proposed no less than 6 specialized PhD courses ranging from Room Acoustics to Acoustic Remote Sensing. Admittedly the number of students per year taking a PhD in acoustics is low, so that each course was not offered every year. Moreover, the Norwegian organization in charge of the quality of education issued recommendations about the content of the PhD course. They recommend that PhD courses should be quite general and not contribute to the specialization of the candidate. As a consequence, since 2020 the Acoustics group offers two PhD-level courses. The first one named Theoretical acoustics deals with general acoustics but at a more advanced level than TTT4180. The second one is called PhD Seminars in acoustics where the PhD candidate will identify three topics of interest that the candidate will investigate by her- or himself through the self-study of chosen reading material. The candidate will present each topic individually in a dedicated seminar.

5 Facilities for hands-on learning

5.1 Rooms and large equipment

The Acoustics Group has access to a set of rooms that used to belong to an accredited measurement lab – the Acoustics Hall - that was opened in 1965, as described above, but decommissioned in the 1990s. The facilities include 3 vibration-isolated rooms. One of these rooms is perfect for the demonstration of room modes. Thanks to the decoupling from the rest of the building, these rooms feature low residual sound pressure levels and vibration levels. This is quite convenient both for listening tests and laser vibrometry.

The Acoustics Hall features also a pair of coupled rooms that are used in TTT4250 for the measurement of sound insulation from small wall elements. The receiving room is well suited to the determination of the absorption factor from reverberation time measurements.

Built in 1958 the Acoustic's group anechoic room has just been refurbished. The original room was used on a regular basis in TTT4250, TTT4170, TTT4850 but also in numerous specialization projects and master's theses. The target cut-off frequency for the new room is 100 Hz. The renovated room will soon receive a measurement robot and a state-of-the-art measurement system. The room will be connected to Trondheim's low latency audio network of performance spaces. In the Acoustics Hall, the so-called Antenna Lab is designed to be electromagnetically anechoic. But this room is also anechoic for sound waves above 900 Hz. This is therefore a suitable place for student projects on scale models or ultrasound experiments.

As its name suggests, the AuraLab was developed for auralization purposes. This room received acoustic treatment including absorbers and diffusers and achieves a low reverberation time. The room has no windows in order to also provide a controlled visual environment. It features a 24-channel sound reproduction system that can be operated from a control room. The AuraLab is well suited for listening tests, a common task in TTT4850, and in individual student projects. It is also used for demonstrations in TTT4170.

When it comes to underwater acoustics, a water tank is also part of the Acoustics Hall. The equipment is used in TTT4250 in the study of ultrasound transducers. TTT4175 students take a one-day cruise on the R/V Gunnerus, the research vessel owned by NTNU, where the students carry out underwater communication experiments or other measurements with underwater transducers at this occasion.

5.2 Measurement equipment

Students taking courses in acoustics have an easy access to various sound sources, sensors, signal conditioners, field recorders, sound level meters and data acquisition systems. A laser vibrometer is used in TTT4170-related lab. In TTT4250, the lab on sound power has the students use a sound intensity probe.

The Acoustics Hall hosts also a standing wave tube with an 800 Hz higher cut-off frequency that takes 20 cm x 20 cm samples. The tube works both for absorption and transmission measurements. It was also extended for the investigation

of silencers. The access to this tube is limited to student projects while a smaller cylindrical tube is used in the TTT4250 lab on the impedance of materials. A test rig for the measurement of flow resistivity is also available.

The amount of equipment that is suitable for outdoor measurements like in sound emission or sound propagation experiments has been however quite limited. But the Acoustic group is in the process of purchasing a multichannel weatherproof data acquisition system, in combination with equipment for the measurement of the vertical sound speed profile in the lower atmosphere. Weatherproof equipment is a key issue because the students often need to make measurements either relatively late in the Fall semester or early in the Spring semester, when the temperatures are low and snow is not unlikely.

6 Studying acoustics with various backgrounds

6.1 The standard way

As indicated above, the education in acoustics offered by the acoustics group is proposed as a specialization in the 5-year MTELSYS programme or in the 2-year MSELSYS international master's programme. Regarding the 2-year programme; while there is no mention of acoustics in the name of the programme, one of seven programme options is called "Acoustics", for which the students can choose exclusively acoustics-related courses over these two years. The same applies to the two last years of MTELSYS. In the review above there is ample choice and possibility to specialize within the specialization in Acoustics, for example towards underwater applications with TPG4100, TTT03+TTT19.

6.2 From physics

The students taking the 5-year MTFYMA programme in physics and mathematics appear to have a very good background if they are interested in acoustics. They enjoy also a lot of flexibility in the courses they can select. Moreover, a physics student can take a master's thesis in acoustics.

6.3 From civil engineering

From Fall 2020, students in the 5-year Civil and Environmental Engineering programme (MTBYGG) will have the possibility to combine TBA4167 (sem. 7:S7), TTT4250 (S8), the new course TTT4285 (S9) and a master's thesis in acoustics (S10). Although the possibility to take even more courses in acoustics for these students would be desirable, the combination of these courses is quite relevant for someone who wants to pursue a career as a noise consultant in the building sector. A challenge is that building acoustics and other acoustics courses are available only for students of the profile "Building and construction engineering" but not the profile "Structural engineering" even though the latter involves many calculation methods.

7 Challenges

7.1 Struggling students

7.1.1 Calculus and complex numbers, signal processing

Acoustics appears to be a relatively mathematics-intensive discipline with the use of differential calculus and of complex numbers in a few courses. Not all study programmes use complex numbers after the initial mathematics courses, which leads to challenges in the acoustics courses. Also, signal processing concepts are used in several courses, and these concepts are not taught in all study programmes.

7.1.2 Programming

As mentioned, several of the courses taught by the Acoustics Group include labs, field work and/or numerical exercises. Therefore, the students have to write code in order to perform calculations or process measurements. The relevance of programming skills is even more important during the master's thesis. In general, the programming skills are not very high but the labs help the students evolve better programming practice. NTNU has recently made a transition to using the Python language for general programming courses, and Matlab is not used at all in any of the first years. Still, many

courses in the last years still employ much Matlab code, and this has increased the programming challenges somewhat for the last-year courses.

7.1.3 Practical skills

The various labs and field work proposed in the courses appear to be quite beneficial to the students in acoustics. The path of the signals in the circuit of connected measurement devices is not obvious to everyone. It helps the students getting more familiar with the technology involved in the operation of sensors and data acquisition systems. The deployment of various measurements systems gives the students opportunities to develop troubleshooting skills and to learn how to manipulate fragile objects like microphones.

7.2 The transdisciplinary nature of acoustics and administrative issues

Nowadays acoustics is obviously not big enough a subject to consider creating a dedicated faculty nor a dedicated department. Departments of acoustics existed once, though, at a number of universities in Scandinavia, including NTNU, but they were eventually merged into larger structures with broader scopes than acoustics. The spectrum of the applications of acoustics is, however, extremely wide. This means that the education offered in acoustics never fits perfectly in any given faculty. In addition, the size of the acoustic component in a faculty may by the one of a minority. This can have obvious consequences, as discussed further below.

7.2.1 The content of a full master in acoustics in a master in electronics

The first consequence is the visibility of acoustics at the faculty and even the department level. At NTNU, the Acoustics Group belongs to the Department of Electronic Systems (IES), that is part of the Faculty of Information Technology and Electrical Engineering (IE). Study programmes appear to be defined at the department level. For practical reasons, the trend is to favour a lower number of larger study programmes. It is then not surprising that IES will propose a bachelor programme in electronics, the 5-year master MTELSYS and the 2-year master MSELSYS already introduced. Acoustics is not mentioned in the names of the different study programmes. There are certainly good reasons for that. But even though the content of a full master in acoustics is offered during the two last years of MSELYS and MTELSYS, these degrees are not considered degrees in acoustics by search engines. Therefore, the visibility of the Acoustics specialization in these programmes is rather low. This is especially critical for MSELSYS that is supposed to attract foreign students. Moreover, by nature MTELSYS will recruit students with an interest in electronics. Choosing acoustics as a specialization in MTELSYS can be seen as a reorientation, not the normal course of events. This means it takes some further effort to convince the students that Acoustics is something to consider. In addition, many potential students that might be interested in acoustics, but without an interest in electronics, will probably not discover the possibilities at NTNU.

7.2.2 Student mobility between faculties

Returning to the fact that acoustics will never fit perfectly in the academic field covered by a faculty, although there are fruitful interactions between electronics and acoustics, for example in the design of sensor systems or underwater communication, there are many other aspects of acoustics where a more general background in physics or a background in civil engineering would be more relevant. An immediate answer would be that for instance a student from civil engineering has the opportunity to apply to the MSELSYS and choose the appropriate specialization. Here the challenge is the priority given to 5-year *siv. ing.* programmes. The student in civil engineering is very likely to have enrolled in such a 5-year programme. Having passed the equivalent of 180 ECTS at the end of the third year is not recognized as the equivalent of a bachelor's degree which means that the student will not be qualified for a 2-year master's of science. If he/she were allowed to enroll, the student would have to give up the *siv. ing* status that is attached to a full 5-year programme the content of which is well defined. An exception to this rule exists: a two-year master's programme called Entrepreneurship accepts students after three years of the five-year engineering programs, and those students get the equivalence of a five-year master's degree in the end. These limitations do not prevent students from other faculties than IE to take acoustics courses, and quite a few such students do so. But this is not always easy because of occasional collisions between courses, since inter-faculty course coordination has limits.

8 Conclusion and perspectives

The history of acoustics teaching at NTNU is more than 50 years long. In this international year of sound, NTNU offers a wide portfolio of courses in acoustics. Some of them are quite unique in Scandinavia. Students who take acoustics at NTNU have easy access to various up to date experimental facilities and equipment that create a very favourable environment for hands-on learning.

The number of acoustics students has been fairly low in the past years. This is partly due to a lack of visibility of acoustics in the study programmes offered by NTNU and the limited possibilities of student mobility between faculties. Nevertheless, one can expect that acoustics will benefit from the high attractivity gained recently by the MTELSYS programme and by the increase in the number of admission places in the MSELSYS MSc programme. If the total number of students reaches the critical mass of about 20 students, creating an independent 2-year master programme in acoustics will become an option to consider.

In the short run, for civil and environmental engineering students, the new course entitled Acoustics of the Built Environment is quite relevant for a career as an acoustics consultant. It is also expected that the Bioacoustics for biodiversity will attract a few students in biology/ethology/ecology.