Danish Sound Technology Network

POSITION PAPER

ICT RESEARCH IN DENMARK

POSITION PAPER ON DANISH SOUND TECHNOLOGY RESEARCH

Editors

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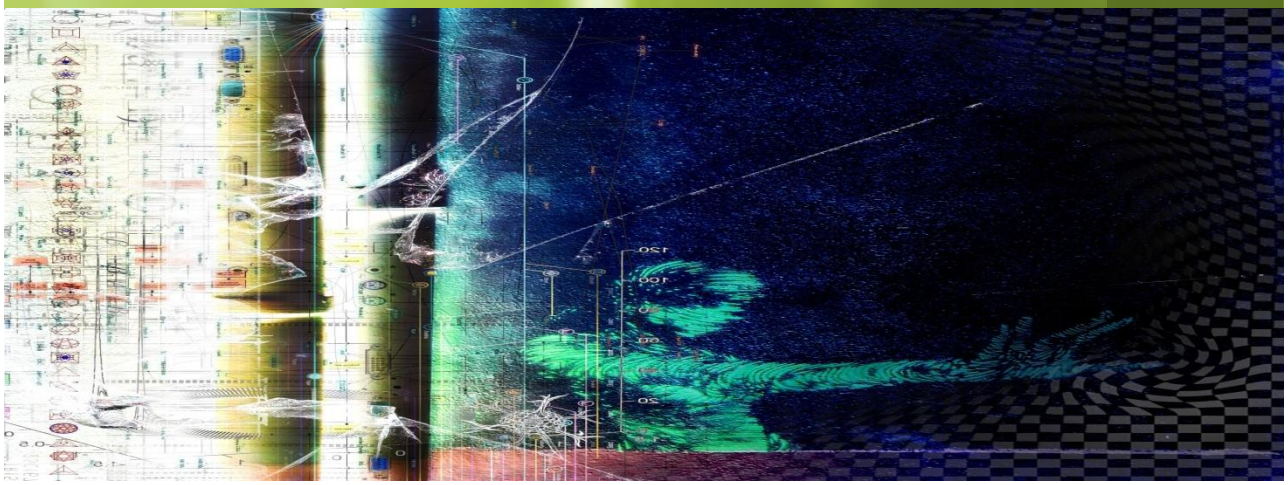

The present paper is part of a series of position papers commissioned by and comprising the collective output of the DICTAT (Danish ICT Ambassador Taskforce) of DI-ITEK to establish a common frame of reference for present and future alignment of Danish ICT research with European research areas, policies and agendas. The paper presents a summary of the position and includes the identification five positions of strengths: Sound recording and reproduction; Diagnostic and monitoring systems; Digital media systems; Designed sound scapes and sound branding; Assistive technology and medical devices. It is a general recommendation that Danish and EU policies should support and facilitate the transformation from classical acoustics, signal processing and transducer technology to multi-disciplinary collaboration in information processing, human computer interfaces, psychology, social network models and adaptive multimodal interfaces.

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This publication and possible comments and discussions can be downloaded from www.soundtechnology.dk.

The content of this publication reflects the view of the Danish Sound Technology Network. We would like to acknowledge valuable contributions by our members, the steering committee, participants of the Positions of Strength Workshop 31.05.2011, and the Confederation of Danish Industry (DI).

About the network

Danish Sound Technology Network is an innovation network funded by the Danish Agency for Science, Technology and Innovation. The Network is hosted by the Technical University of Denmark and is headed by Director, Associate Professor, PhD Jan Larsen.

The vision of the network is that Denmark is a leading country with regards to sound technology in terms of knowledge, research and education. Danish sound technology will be the epitome of high quality in products and services, as well as in physical rooms and social contexts. Sound technology is a broad field involving many traditional business areas and has the characteristics that sound is part of the problem or solution.

Network membership is free of charge and open for all. Registration at www.soundtechnology.dk

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Part 1: Sound Technology – context analysis

Introduction

The present paper is part of a series of position papers commissioned by and comprising the collective output of the DICTAT (Danish ICT Ambassador Taskforce) of DI-ITEK to establish a common frame of reference for present and future alignment of Danish ICT research with European research areas, policies and agendas.

Denmark is world renowned for our audio ICT today due to a strong research tradition and an aptitude for combining disciplines. The main subjects in sound technology are acoustics, psycho acoustics, electrical engineering, computer science, signal processing, and machine learning and they are being employed in various research fields such as hearing aids & medical devices, sound effects, hi-fi and music equipment, telecommunications, sound measurement, and defense industry. Our skills in creating multi-disciplinary approaches and projects that combine different research fields will be even more demanded in the years ahead as the separate technologies will need to undergo a transformation to adjust to the scenarios of the future. This need for transformation is central to understanding the challenges we face and therefore central in this position paper.

Sound technology, as such, covers a larger area than simply audio technology and includes technologies related to noise, sound identification, security etc. as well as audio technologies associated with recording, manipulation, mass-production, and distribution of audible sound.

The focus in this paper is sound technology, characterized by the fact that sound is a part of the problem or solution, and the main attention will be on the challenges in audible frequency range: from 20 Hz to 20 kHz. Thus ultra sound will play minor role. That being said, a lot of the ICT technologies regarding sound can be used equally well on sounds with frequencies within the limit of human hearing as on sounds with frequencies above.

The Danish Sound Technology Network, author of this paper, is an organization that facilitates cooperation across different professional approaches and private and public R&D groups. We are a focal point for all the relevant stakeholders in sound technology and with over 500 individual members we have the necessary background knowledge to survey Danish audio ICT and give an overview of the current position. There is a factual description of the network in the second part of this paper.

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To understand why Denmark has a unique position in sound technology you have to consider the past. Historically, the many Danish contributions in sound technology research since the 1930's are in large part due to the facts that acoustics where established as a research field at the Technical University of Denmark (DTU) early on. In the 1930's Professor P.O. Pedersen coined acoustics as a prosperous future for young engineers, including his students Brüel, Ingerslev and Jordan. This became the starting point for a series of highly successful companies.

1941 was the year Lydteknisk Laboratorium (Sound Technology Lab) was established by the Academy of Technical Sciences. It was headed by Fritz Ingerslev from 1945, and in 1954 he became professor of electro acoustics at DTU. At the new DTU campus in Lyngby Prof. Ingerslev established the new acoustics laboratory facilities in 1963 which included world class anechoic chambers and reverberation chambers.

It is no coincidence that the Danish audio industry was also established in the same time period. In the first half of the 20th century prominent companies such as Bang & Olufsen, Brüel & Kjær, Danavox (GN Resound), William Demant (OTICON) and Tøpholm & Westermann (WIDEX)[1] were founded. Today the three hearing aid companies control over 40% of the world market for hearing instruments.

A report from 2006 based on the industrial/business classification codes states that Danish sound technology companies span 48 business branches and were involved in producing a turnover of more than 2.7 billion Euros of which 80% was export (2005 figures).

Danish positions of strength

The Danish Sound Technology Network has identified five positions of strength where companies and knowledge institutions distinguish themselves.

Sound recording and reproduction	•Professional live sound systems •Hi-Fi systems •Class D amplifier systems
Diagnostic and monitoring systems	•Environmental sound analysis •Forensics and surveillance •Measurement systems
Digital media systems	•Organization and retrieval of music and sound and semantic audio •Professional broadcast production systems •Home entertainment systems incl. gaming
Designed sound scapes and sound branding	•Sound communication •Sound for electric cars
Assistive technology and medical devices	•Hearing instruments •Assistive sound in the medical care sector

The descriptions in the paragraphs below list some of the players in each position of strength. The descriptions are by no means exhaustive and other relevant organizations are not mentioned.

In position 1, companies such as Bang & Olufsen, DALI, and Steinway Lyngdorf excel in production and design of high quality loudspeakers and B&O also stand out in production of Hi-Fi systems. The successful enterprises in respect to Class D amplifiers are Bang & Olufsen Icepower as well as Texas Instruments Denmark and Pascal. TC Electronic should also be mentioned in connection with professional live sound systems.

In environmental sound analysis related to position 2, the section for Acoustics at Aalborg University as well as DELTA (GTS Institute) delivers high quality analysis. In the private sector COWI, a leading international consulting firm, is also renowned and much recognized for its environmental studies. Rambøll provides services in acoustical consulting associated with construction and design, infrastructure and industry and have more than 200 offices in 23 countries.

[1] Bang & Olufsen (1925), Brüel & Kjær (1943), Danavox (1943, today GN Resound), William Demant (1904, today OTICON) and Tøpholm& Westermann (1956, today WIDEX).

Brüel & Kjær is successful in environmental monitoring and among the world leading suppliers of sound and vibration tests. In regards to forensics and surveillance, one could also mention the Aarhus based company Terma and their successful surveillance products and the one-man company EBB Consult.

Position 3 concerning digital media systems is an area where ICT competences play a major role. In terms of the educational and research basis the Cognitive Systems section at DTU Informatics as well as the section for Multimedia and Signal Processing and Media Technology at Aalborg University delivers very strong candidates in this field. In the private sector Bang & Olufsen has new strategic goals to focus on systems integration, user experience and digital media products among others and there are several successful smaller companies such as Syntonetic with their intelligent music player Moodagent.

Position 4 (as well as 3) is not an established position of strength in the Danish private sector per se, but both fields are rapidly emerging. The design and branding of sound is becoming a recognized field and smaller companies, for instance Soundbranding, Audiowise, SoundFocus, and ECTunes are pursuing new domains where the adding of sound creates new opportunities and markets.

Area 5 is one of the most successful in sound technology. The three leading hearing aid companies, Oticon, Widex and GN Resound, cover a large percentage of the world market and there is critical mass in terms of both research environments and private corporations. Adding to that, Denmark has strong research groups on the fields of sensors, optimized acoustic environments as well as in ultrasound.

Sound technology research challenges and competitive perspectives

As mentioned in the introduction, sound technology is a more useful term than audio technology as it is inclusive and allows for more ICT perspectives, especially in regards to signal and information processing. In traditional sound technology mainly three areas are in play: Signal processing, transducers and acoustics. The best way to view the research challenges is to investigate challenges facing these three domains.

Technological challenges

Sound signals do not occur in a vacuum, but as part of a context, an environment, and a social construction. This has become gradually more apparent in upcoming products. The time where products and services were stand-alone is over and they are now required to interact and be able to adapt to the context in a network of other products and services. This creates new needs for understanding users and integrating psychology, HCI (human computer interaction) and social network models in the research and development phase. In addition to this there are still open questions as to how the influence between many modalities works (feeling, vision, hearing, smelling, and cognitive abilities) and what impact this has.

Many perception- and cognitive-related aspects of sound technology need to be resolved, and this will in many cases require multi-disciplinary approaches. This may be particularly relevant in the context of building machine hearing systems that can mimic human performance on as many auditory tasks as possible. Immediate applications are in e.g. the automatic evaluation of audio quality. Related to this is the "semantic gap", the discrepancy that exists between what can be identified in musical signals as opposed to what humans perceive. That gap needs to be bridged. In terms of products and services this might improve product quality control where a scientific challenge may be to develop a multi-attribute analysis for quality control (QC) and monitoring to enhance quality of products.

Likewise, sound from the environment that surrounds us is becoming an information source useful in identifying our needs or feeding information to sensors or transducers for registration or experience

enhancement purposes. The mobile phones we all carry today already have many of the sensor or recording capabilities available, but the potential uses have yet to be integrated. In terms of research, the measuring and characterizing of spatial sounds, objectively as well as subjectively, around products and in the environment is one of the challenges in this area. Understanding when and how people decide whether they like the sound or not is yet another one.

The movement away from stand-alone products has a large competitive impact and although Denmark is leading in many areas within audio, the future will depend much on options for integrating functionality, since the technology platforms become more and more advanced, and also consumers are less likely to buy dedicated hardware solutions for audio. Fields of relevance could be:

- Better coupling of acoustic measurement and simulation, e.g. in structural analysis.
- New sound and vibration sensing technologies and transfer of data.
- Bluetooth protocols and thorough requirements specification (+ test specifications).
- Focus on user friendliness. Inclusion of the non-professional.
- HDMI and Blu-ray are developing too fast for smaller companies to keep up and solutions are needed.

The focus on solutions, functionality and services rather than on specific sound technology components in sound and test measurement systems involves the inclusion of the environment in which the user works and the working/leisure experience.

Another area with growth possibilities relates to measurement and assessment methods for noise. During the last century, a universal weighting function was agreed upon, and this led to the current A-weighting. It is widely known and accepted that the A-weighting has it shortcomings, and many standards and guidelines include various “penalties” for situations, where the A-weighting does a particularly poor job. It is time to investigate options on a larger scale, and possibly come up with alternatives. In the US a quite different alternative has been developed based on neurophysiological data (from animals). This assessment method is specific for impulsive noise (in the military), and as a result fewer individuals receive compensation for the hearing losses inflicted in conflict situations. It is desirable to have algorithms that integrate the full range of possible agents, including noise from industry, music, gun-shots, etc.

Social challenges

In terms of social perspectives there are numerous areas where sound can be integrated more fully. One of the issues facing us is “The Information Society” where the amount of data is increasing rapidly. There is a need for technical solutions in order to assist categorization of the many media files online and in archives; both regarding record preservation and recommendation systems.

Another obvious social challenge is the change in the European demography towards a larger proportion of elders and this is an area where sound technology has apparent application potential. Assisted Living is one domain where new and innovative ways of integrating sound might be useful, e.g. in the registration and identification of movements or in interaction/communication with the environment. There is a need for continued development of hearing aids as a larger part of the population will be subject to age-induced hearing losses (presbyacusis). This calls for better technologies in hearing aids (e.g. connectivity) and new features to improve life quality even for those with mild hearing losses as well as a break with the social stigma connected to hearing loss.

Nowadays, hearing aids are designed for and offered to individuals with hearing problems. Because of the higher risks for noise induced hearing losses in younger people from contemporary music players and

excessive use of high level sound in leisure and entertainment, the population of hearing aids users may therefore change and increase. This could call for a change in the development of design, algorithms, flexibility etc. Also, the increased use of earphones may enable a change in the Hi-Fi market and the development of devices which can be integrated with smart phones etc. while still allowing ambient sound to pass naturally.

Related to the hearing loss due to noise a further social and scientific challenge is the general increase in environmental noise and the following occupational health concerns and impacts due to long time annoyance exposure (e.g. windmills, new power technologies, public transport, transportation, etc.). There are several scientific domains here and vast potential for multi-disciplinary efforts in for instance new analysis methods and management strategies, equipment to quantify impact of next generation transportation equipment (green, hybrid, electrical, low noise airplanes), new engines, new materials, increased public transport, suppression of traffic noise etc.

State-of-the-art and trends

It is tempting to associate state-of-the-art sound technology to the state-of-the-art on digital audio technology. Digital audio technology has made an enormous impact on the evolution of sound technology and evidence of this is observed in the advances in audio coding ranging from Hi-Fi audio formats (e.g. Blu-ray) to audio compression schemes (e.g. MP3, AAC) whose use is ubiquitous in portable, networked and wireless audio devices (e.g. portable media players and smartphones); gain control, active noise and echo-cancellation for applications in digital communication devices and digital hearing aids; physical modeling, perceptual modeling and digital filtering techniques on computer simulations of room acoustics; integration of audio technologies for the development of standards addressing analysis, synthesis and classification of multimedia content (e.g. MPEG-4, 7 and 21).

Another trend in sound technology is the translation of the measurement of the physical sounds and vibration into the perceptions of sounds and vibration using psycho-acoustic/perceptions methods and metrics. In this area assessment of sounds over the internet for subjectivity is also a feasible tool.

Using the internet to transmit sound is most certainly a trend in itself and there are various uses of wireless technologies emerging everywhere. Sound and vibration can be transmitted all over the world in real time and assessed in many places simultaneous, objectively as well subjectively. Low-power wireless technology ensures interconnectivity (e.g. Bluetooth mobile phone, etc.) and enables further integration of computers, phones, smart phones, television, and video playback systems.

The improvement of communication systems that attempt to integrate knowledge on the way we perceive sound in a multimodal environment is another example of state-of-the-art. In further developing applications such as teleconferencing for instance, a physical room must be enabled so that multimodal interaction between physical and virtual participants is possible. This will require the intelligent combination of spatial sound technologies and room acoustics, such as we have seen in the latest surround receivers with room acoustic compensation and space correction, with technologies developed for vision and haptics. In order to transmit sound events which can be shared by the physical and virtual parties, protocols must be defined that integrate the real-time capturing, transmission and rendering of not only sound material but also parameters such as, position of real and virtual participants, moving and positioning of audible objects and room parameters.

The potential of sound as an agent for orientation and information combined with the increased use of wireless portable audio devices, the increase in storage capacity and processing power will lead to further developments of the so-called “wearable audio”. This type of application will enable artificially generated sound to be seemingly combined with natural listening with the purpose of complementing and probably enhancing the way we experience our real-world sound environment.

Another state-of-the-art area is connected to automobiles and the focus on top-quality sound reproduction in cars in all price categories (automotive infotainment). This is connected with add-on sound in electrical cars, the measurement and production of car sounds, etc. The use of sound in the automobile industry is a trend area.

Danish competences and interests

The five Danish companies with the most global recognition within sound technology

When asking our members this question there was a general agreement that the hearing aid companies (all three, but Oticon in particular) and the high end audio/video product company Bang & Olufsen was among the five. Brüel & Kjær Sound & Vibration and TC Electronic were also mentioned in many of the replies and that concurs with our understanding as mentioned in the second chapter. Among the runners up are DPA Microphones, Nsaka, G.R.A.S, Lyngdorf Audio, Jamo, Scanspeak, Ortofon.

Short descriptions of the companies:

Bang & Olufsen develops, manufactures and sells a wide range of luxury audio/video products, including television sets, music systems, loudspeakers, telephones and multimedia products that combine new technology with stylish design, quality and user friendliness.

Oticon is part of the William Demant Holding Group, one of the world's leading manufacturers of hearing aids. It is a Danish owned company with more than 5,300 employees worldwide and revenues totaling USD 1 billion. Oticon's products are distributed in more than 100 countries, and 97% of Group revenues are generated outside Denmark. The group consists of companies developing and producing personal communication devices, diagnostic instruments and hearing instruments.

Widex is founded by the Tøpholm and Westermann families. The company is owned and run by the second family generation. It has representation in more than 100 countries in all parts of the world and the global market share is approximately 10%. The company employs 2,600 worldwide, 800 of these in Denmark. The production is placed in Vassingerød and Helsinge, Denmark, as well as in Verviers, Belgium.

GN Resound is headquartered in Ballerup, Denmark, and is part of The GN ReSound Group, one of the world’s largest providers of hearing instruments and diagnostic audiological instrumentation which in turn is part of GN Store Nord. ReSound is represented in more than 80 countries and draw on a vast pool of resources at technology centers around the world.

Brüel & Kjær Sound and Vibration Measurement supplies integrated solutions for the measurement and analysis of sound and vibration and delivers advanced technological solutions and products of renowned quality. These cover the entire sound and vibration measurement chain from a single transducer to a complete turnkey system. Brüel & Kjær is a global company operating through a network of sales offices and representatives in 55 countries.

TC Electronic was founded in 1976 with the objective of developing, manufacturing and marketing first class audio products for audio professionals and musicians. The company is very focused on new technologies and products and has approx. 40 R&D staff. Today, the company is not only a leader in digital signal processing, but also a major player in other aspects of the digital audio technology world, such as digital amplification and networking. Based in Risskov, Denmark, TC sells their products through a dedicated sales force in 15 different countries.

Danish national strategies that support the sound technology research

Sound technology as such is not recognized as an independent research area in terms of national strategies. The research conducted in public research institutions is housed in departments with broader scopes, but with sections dedicated to central areas in sound technology, such as Acoustics.

With regards to external funding, the Danish Council for Independent Research (DFF) funds specific research activities within all scientific areas, that are based on the researchers' own initiatives and on improving the quality and internationalization of Danish research. But the inherent cross-disciplinary nature of most acoustic and sound technology projects is not well facilitated in the current setup as it would be in e.g. a national program for acoustics.

In terms of national funding with collaboration from private partners there exist a number of foundations and grants dedicated to either advanced technology, strategic research, or other types of collaborations between companies and research institutions. Among the most relevant are: The Danish National Advanced Technology Foundation and The Danish Council for Strategic Research, both of which are applicable for sound technology research projects.

The Danish National Advanced Technology Foundation: The Danish government supports the advanced-technological efforts through the Danish National Advanced Technology Foundation, whose general objective is to enhance growth and strengthen employment by supporting strategic and advanced technological priorities within the fields of research and innovation.

The Danish Council for Strategic Research: The Council seeks to ensure that strategic research in Denmark is organized to meet the challenges facing Danish society regarding welfare, wealth and science in the short and long term. Strategic research takes place in a problem-oriented context, not a discipline-oriented context. This means that strategic research often spans several disciplines and is carried out in a matrix organization across public and private-sector institutions where disciplines or subjects are included as required.

Other strategies that support projects in general are the Innovation Consortiums, the Open Funds, and the Industrial PhD Program etc.

Finally, there are two centers at respectively DTU Electrical Engineering and the Department of Acoustics at Aalborg University that support sound technology research specifically. The centers are partly financed by private companies and are called “Centre for Applied Hearing Research” (CAHR) and “Sound Quality Research Unit” (SQRU).

The Centre for Applied Hearing Research (CAHR) was established in May 2003 and is home for a research group in DTU Electrical Engineering, which is the electronics engineering department at DTU. This position encourages close cooperation with experts and facilities within the fields of Physical Acoustics, Room Acoustics, Electro Acoustics and more. The centre is supported by the three Danish hearing aid companies Oticon, Widex and GN Resound and their foundations and employs 20 staff members.

The Sound Quality Research Unit (SQRU) was established in 2001, in collaboration with industrial partners, in order to advance basic and applied research in the fields of human sound perception, product sound quality, fidelity of reproduced sound, and instrumental analysis. It is based at the Department of Acoustics, Aalborg University. Partners: Bang & Olufsen, Brüel & Kjær and DELTA.

At last, it should be noted, that the **Danish Sound Technology Network**, editor of this paper, is also a part of the national innovation strategy and is supported by The Danish Agency for Science, Technology and Innovation through their initiative "Innovation Networks".

Recommendations

In terms of recommendations for future research projects, the overall wish from our perspective is to include themes in the future research programs that address more directly the area of acoustics, sound technology and human sound perceptions. Perhaps even recognizes sound/audio technology as an independent research area in ICT.

Our recommendations are structured around the five positions of strength mentioned in the beginning of the paper and include areas connected to the challenges mentioned in the third paragraph.

1. **Sound recording and reproduction (e.g. professional live sound systems, Hi-Fi systems):**
    a) Research in transducer technology and spatial 3D sound (also important in 2).
    b) Research in sound quality evaluation and measurement.
    c) Research in audio streaming technologies.
2. **Diagnostic and monitoring systems (e.g. environmental sound analysis, forensics and surveillance, measurement systems):**
    a. Research in transducer configuration and metrics.
    b. Research in subjective measures of the perception of spatial 3D sound.
    c. Research into areas on source identification using acoustic means.
    d. Research in distributed transducer technologies over wireless networks.
    e. Increased focus on numerical acoustics and the relation to diagnostic and monitoring systems.
3. **Digital media systems (e.g. organization and retrieval of music, and sound and semantic audio, professional sound/media editing for broadcast production systems, home entertainment systems incl. gaming):**
    a. Signal and information processing algorithms for retrieval of music and semantic audio analysis.
    b. Further research in formats of audio coding for network and wireless devices.
    c. Research in user-generated content, crow-sourcing and inclusion of social network models.
4. **Designed sound scapes and sound branding**
    a. Continued research into the perception of sound in general, in psychoacoustics and others (e.g. neuro aesthetics).
    b. Research in the assessment of sound over the internet.
    c. Research in assessment and understanding of environmental sound and how it affects humans.
    d. Research into how sounds can add value to product branding.

5. **Assistive technology and medical devices (e.g. hearing instruments)**
    a. Focus on technical and audio logical research in determining the needs of the hearing-impaired and the development of new signal processing algorithms.
    b. Research in common wireless standard for hearing aids (and other low power).
    c. Create a European interest group for the hearing-impaired (as in the US).

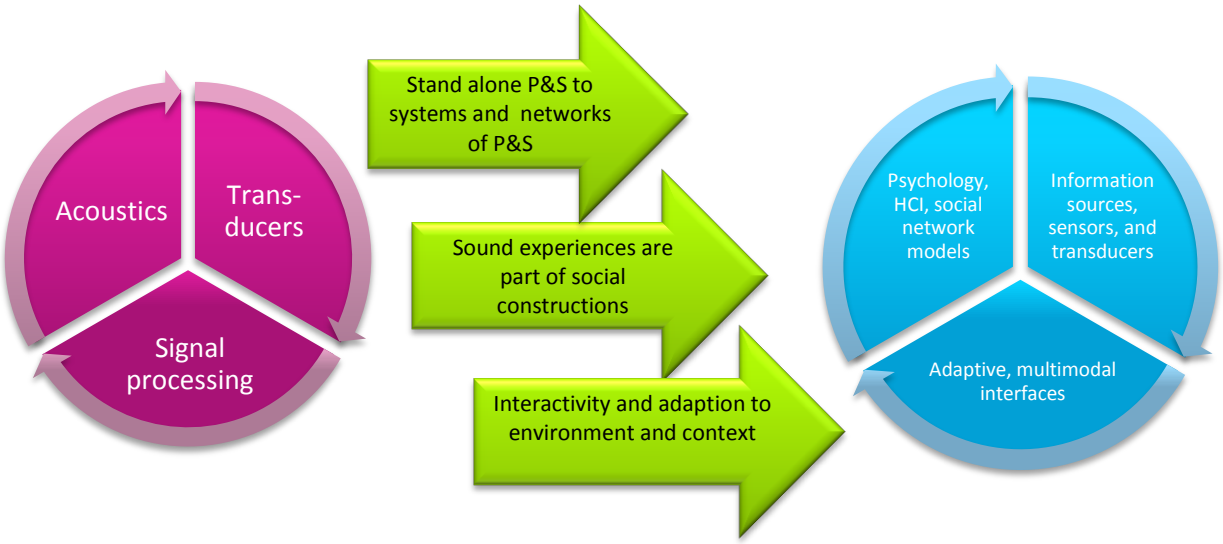
Danish contribution to European research

Denmark has some unique competences that could have a significant impact in an international context. Among them are:

- Interdisciplinary knowledge of psycho-acoustics, transducers, acoustics, signal and information processing, sound quality evaluation and user interfaces.
- Broad and very professional environment in both companies and institutions:
    - Tradition of open networks;
    - Researcher Exchange;
    - High level of multi-disciplinary and collaborative activities between companies and research institutions.
- Knowledge dissemination:
    - Participation in high-level conferences and contribution to research journals;
    - Significant experience with user-generated content.

Improvements of EU/Danish research strategies – *policy recommendations*

The EU as well as the Danish research strategies should support the transformations of the classic strengths connected to transducer technology, acoustics and signal processing in their programs. This should be done by creating structures and calls that support inclusion of new areas of competence and efforts that include a tighter integration of audio and other information sources, psychology and social network models as well as adaptive multimodal interfaces. This needs to happen in recognition of the global mega-trends and the challenges that the sound sectors face such as the facts that systems are connected in networks; the audio experience is a part of social constructions, and the need for extensive interactivity and adaptation to the context and those surroundings in which the product or service must operate in.



In addition it is suggested that EU and Danish research strategies take under consideration the following points:

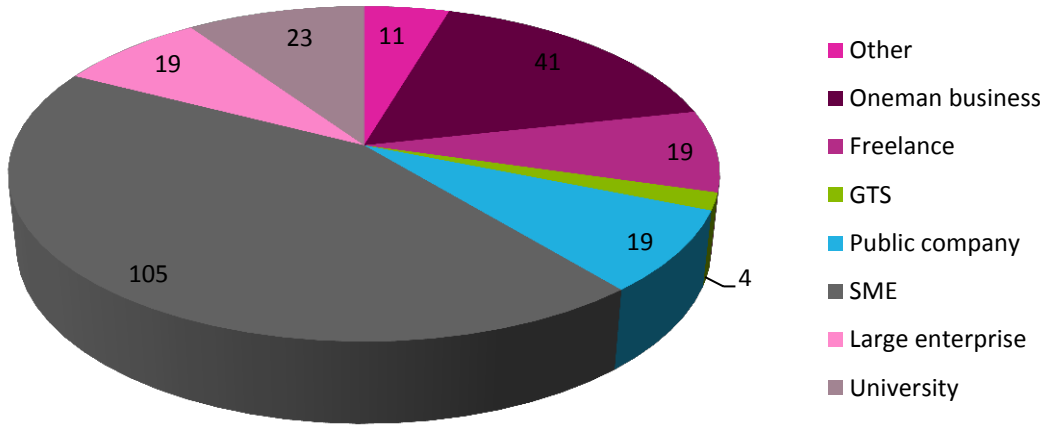
- Changes in focus:
    - Increase application oriented focus in specific programs.
- Improve exposure/visibilities:
    - Facilitate ambassadors with strong international reputations (e.g. research centers CAHR, SQRU mentioned above).
    - Danish sound technology should be more visible in an international context, e.g. by forming strong research clusters.
- Influence standardization processes.
- Research frameworks:
    - Easier access for companies to involve universities in basic research.
    - Continued programs that support sound technology research, especially when situated in a multimodal and multi-disciplinary context.

Part 2: The Danish research positions

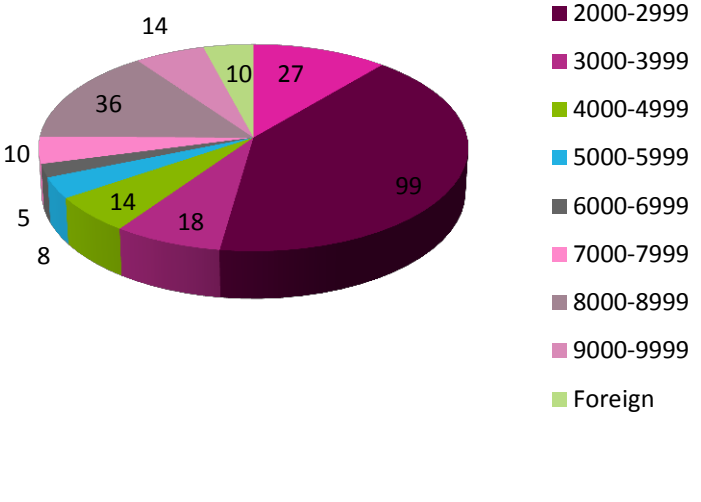
Danish Sound Technology Network

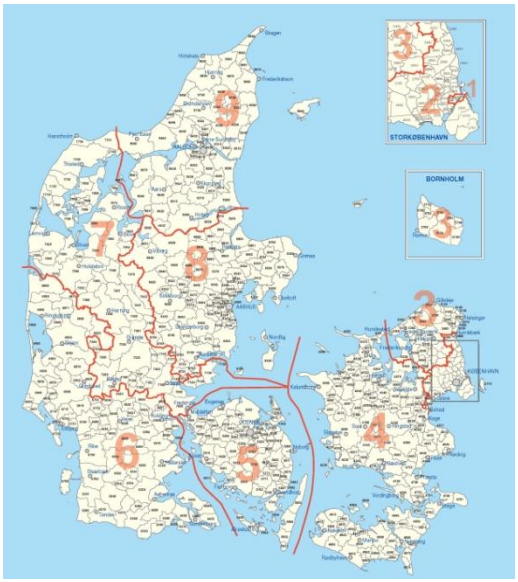
The network is comprised of approximately 530 individual members from all sectors involved in sound technology. Not all of our members are engaged in research and development, but all of them have a vested interest in the technological development connected to sound and audio. The members come from around 241 organization categorized as shown in the pie chart below. As the network is national the organizations come from all parts of Denmark, but the majority is centered in Copenhagen and the surrounding country. A large number of the members are also located in the northern part of Jutland in the postal codes from 7000-9999 (see the map and chart). Coincidentally, these are the two locations hosting the universities with the highest number of research man-years in sound technology. In Jutland the strong points are connected to loudspeaker technology and different areas in telecommunications. In the area surrounding the capital the picture is more dispersed.

241 organizations in the Danish Sound Technology Network



Postal codes of Danish Sound Technology Network organizations





Universities and research institutions conducting research in sound technology

Sound technology research as such is conducted in several of the Danish Universities, but the main activities take place in four central research institutions; three universities and one GTS institute (Advanced Technology Group).[2]

The Universities are the Technical University of Denmark (DTU), Aalborg University (AAU), and the University of Southern Denmark (SDU).

At the **Technical University of Denmark** sound technology plays a part of a wide range of projects but is mainly conducted at the Department of Electrical Engineering in three research groups: Acoustic Technologies, Hearing Systems and Electronics. The research in Acoustic Technology is focused on generation and transmission of sound, passive and active noise control, advanced acoustic measurement techniques, transducer technology, room acoustic modeling and design, and effects of new building materials on sound transmission. The research in Hearing Systems focuses on auditory and speech processing and perception, functional models of hearing, audiology, physiological acoustics, objective measures of hearing and hearing instrument signal processing. In the last group, Electronics, research in sound technology is but one of many focus-areas and is connected with their research in power and switch-mode power technology, in particularly in Audio Amplifiers.

DTU Technical University of Denmark

DTU Informatics
Cognitive Systems
DTU Electrical Engineering
Hearing Systems
Acoustic Technology
Electronics

At DTU Informatics, a department dedicated to computer science and mathematical modeling, sound technology research is conducted in the Section for Cognitive Systems. The section study information processing in man and computer, with a particular focus on the signals they exchange – audio, images,

[2] GTS - Advanced Technology Group is a grouping of nine independent Danish research and technology organizations (the GTS institutes). They develop and offer state-of-the-art technological services. Read more at www.teknologiportalen.dk

behavior – and the opportunities these signals offer for modeling and prediction. With regard to sound technology the main issues are methods and systems for audio analysis, audio search, information retrieval, cognitive modeling, mobile services using signal processing and machine learning and HCI.

Aalborg University houses three research groups involved in sound technology research. The Acoustics group and the section for Multimedia and Signal Processing (MISP) are situated in the Department of Electronic Systems. The section for Media Technology belongs in the Department of Architecture, Design & Media Technology.

Department of Electronic Systems
Acoustics
Multimedia Information and Signal Processing

Department of Architecture, Design & Media Technology
Media Technology

In the section for Acoustics the research is focused on acoustics and sound in a broad sense, including generation, transmission and propagation of sound, human sound perception, electronic systems for measurement, processing and analysis of sound, reproduction of sound, in particular including the binaural technique for generation of three dimensional sound, measurement of noise, audio systems etc. Apart from electro-acoustics, psychoacoustics and physical acoustics these fields also include analogue and digital signal processing and construction of necessary equipment, for instance when carrying out listening tests.

The Section for Multimedia Information and Signal Processing (MISP) focuses its research on multimedia technologies, primarily speech, language, and audio, and the sciences that support them. Among the research areas are the design and evaluation of multi modal user interfaces, with a special focus on mobile devices. MISP draw concepts from fields such as numerical linear algebra, optimization, statistics, signal processing, pattern recognition, machine learning, speech and language processing, software engineering, and usability engineering.

The third research group in sound technology at Aalborg University that embraces sound technology is focused on areas such as Human-computer interaction, audio-visual effects, human perception, immersive computer systems and new enactive interfaces. This group is engaged in a many multidisciplinary projects and only some concerned with sound technology research.

At the **University of Southern Denmark's** Faculty of Engineering sound technology research is conducted at the Institute of Sensors, Signals and Electrotechnics (SENSE). It is only one of several research areas at SENSE and their competences are mainly in sensor technology and signal processing. The research is focused on optical sensors, acoustic and ultrasonic technologies, methods and use of signal processing as well as thermography and microwave technologies. SENSE also conducts research in power electronics, actuating devices and control engineering in, for instance, supply networks and security, energy technologies and modeling of power components with, for example, the estimation of remaining useful life and quality in mind.

Faculty of Engineering
Institute of Sensors, Signals and Electrotechnics

The GTS institute mentioned above is called **DELTA** and consists of separate business units that specialize in electronics, microelectronics, light, optics, acoustics, vibration and sensors. The institute does not conduct basic research and as a private independent consulting firm, its main focus is to develop and sell technological services to private enterprises

SenseLab
Acoustics

and public authorities.

Number of publications and citations

We have used Google Scholar to research publications and citations as it gave the most results and had the best search options. We chose to enter relevant search word associated with sound technology as well as the names of the significant Danish research institutions. This way we were able to create an overview of some of the articles published within the research area regardless of whether the researcher was still employed in Denmark now. In the search we chose to focus on the period from 2004 to 2009 to have enough data for a credible pattern and to restrict ourselves to recently published papers. Afterwards we made some tests comparing our list to the researchers own publication lists at their website, and it is clear that Google Scholar cannot deliver the complete catalog of publications, but merely an indication. Whether the search engine gives the correct number of citation we do not know.

Below you see the combined results from all areas within sound technology from the two main research institutions, the Technical University of Denmark (DTU) and Aalborg University (AAU). As mentioned above, the searches do not include all articles, and should not be considered an estimation of the productivity by the Danish researchers. The stats include both the tenured professors with many publications and citations and the Ph.D. students without citations. The average citation and the average number of papers cited connected to the two research institutions are very similar and indicate that in terms of impact AAU and DTU are on the same the level overall with regards to sound technology.

Organization	Years	Google scholar documents	Times cited	Cites per document	% document cited	Average cit. pr. docu.	Average % cited
DTU	2004	29	152	5,24	86%	5,55	74%
DTU	2005	31	347	11,19	90%		
DTU	2006	38	264	6,95	82%		
DTU	2007	46	237	5,15	67%		
DTU	2008	46	133	2,89	72%		
DTU	2009	25	47	1,88	48%		

Organization	Years	Google scholar documents	Times cited	Cites per document	% document cited	Average cit. pr. docu.	Average % cited
AAU	2004	34	246	7,24	91%	4,72	73%
AAU	2005	58	401	6,91	83%		
AAU	2006	45	147	3,27	69%		
AAU	2007	34	197	5,79	71%		
AAU	2008	46	159	3,46	70%		
AAU	2009	52	87	1,67	56%		

EU projects with participation of Danish sound technology enterprises and/or universities

From questionnaire answers and EU ICT Research websites we have constructed a list of EU projects with Danish participation.

3 TH FRAMEWORK

HEAR: General hearing-aid processor, GN Danavox (1993-96).

JUKE BOX: Applying Telematics Technology to Improve Public Access to Audio Archives, Statsbiblioteket.

5TH FRAMEWORK

AE-WATT: Marine Power Plant Management and Monitoring Using Acoustic Emission, MAN B&W, DTU.

SILENCE-R: Significantly lower community exposure to aircraft: Brüel & Kjaer Sound & Vibration Measurement A/S.

ARDOR: Adaptive Rate-Distortion Optimised Sound Coder, AAU.

SAFE SOUND: Safety improvement by means of sound, RISØ (Today DTU).

DOREMI: Directionally Optimised Representation of Musical Instruments, DTU.

ACES: Optimal acoustic equivalent source descriptors for automotive noise modeling, Brüel & Kjær Sound & Vibration Measurement A/S.

6TH FRAMEWORK

SILENCE: Quieter Surface Transport in Urban Areas: Bruel & Kjaer Sound & Vibration Measurement A/S.

HEARCOM: Hearing in the communication society, DTU, GN Resound.

SKILLS: Multimodal Interfaces for Capturing and Transfer of Skill, AAU.

MINAMI: Micro-nano integrated platform for transverse ambient intelligence applications, Oticon.

E-NEXT: Emerging networking experiments and technologies, DTU.

EU-FIRE: Innovative optoelectronic and acoustic sensing technologies for large scale forest fire long term monitoring, Brüel & Kjær.

SAFE-AIRPORT: Development of an innovative acoustic system for the improvement of co-operative air traffic management, G.R.A.S.

INQUEST: Information Network for Quiet European Road Surface Technologies, Dahish Road Directorate.

7TH FRAMEWORK

BEAMING: Beaming through augmented media for natural networked gatherings, AAU.

QUASIMODO: Quantitative system properties in model-driven design of embedded systems, AAU.

PASCAL, PASCAL2: Pattern Analysis, Statistical Modelling and Computational Learning, DTU.

WHERE: Wireless hybrid enhanced mobile radio estimators, AAU.

CHIROPING: Developing versatile and robust perception using sonar systems that integrate active sensing, morphology and behavior, SDU.

NIW: Natural interactive walking, AAU.

GREEN CITY CAR: Integrated solutions for noise & vibration control in vehicles, Bruel & Kjaer Sound & Vibration Measurement A/S.

Industrial research

Danish companies with R&D departments with sound technology research

There are only a few Danish companies that conduct high level technological research. The most significant among them are:

Hearing industry: Oticon, Widex, GN Resound, Sonion.

High end audio products: Bang & Olufsen, Lyngdorf Audio, DALI.

Microphones and measurement: Brüel & Kjær, DPA Microphones, G.R.A.S.

Defense and surveillance: Terma.

Telecommunication: RTX Telecom.

Audio processing: TC Electronic, AM3D.

There are other companies with smaller R&D departments, for instance in the loudspeaker industry, but during the last 10-15 years several of the biggest loudspeaker enterprises in Denmark has been sold. This has generated a number of smaller consultancy companies headed by former employees where research and consultancy projects exist hand in hand.

Global marked position for the part of the industry active in sound technology research

The Danish hearing Aid industry is globally dominant with more than 40 % of the market. Oticon is the leading Danish company and number two in the world after Sonova (Phonak). In the sound and vibration measuring market Brüel & Kjær is among the world leaders and G.R.A.S is also doing well with distributors all over the world.

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