Panel 5:
Intelligent Systems and Biomedical Engineering
Self-assessment

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1. Introduction

1.1. Who we are

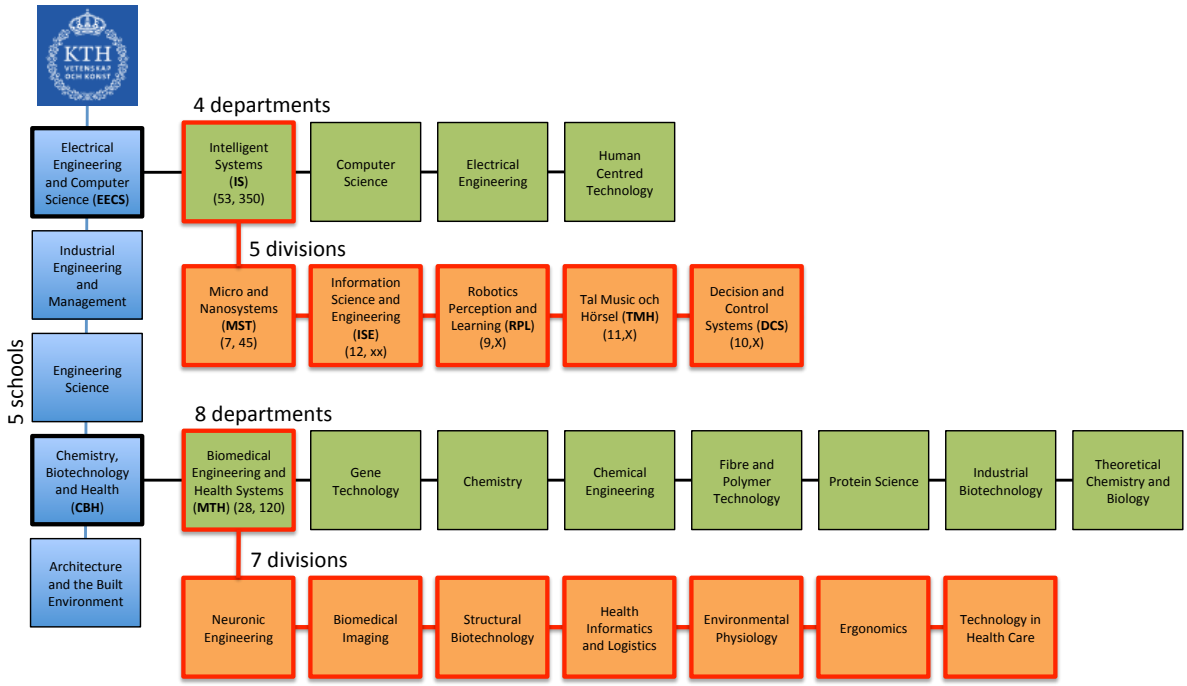
Panel 5 consists of two departments from two different KTH schools:

- the department of intelligent systems (IS) in the school of electrical engineering and computer science (EECS).
- the department of medical technology and health (MTH) in the school of chemistry, biotechnology and health (CBH).

IS has ~300 employees and is organized in five divisions: Decision and control systems (DCS); Information science and engineering (ISE); Micro and nanosystems (MST); Robotics, perception and learning (MST); Speech, music and hearing (TMH).

MTH has ~120 employees and has seven divisions: Biomedical Imaging; Environmental Physiology; Ergonomics; Health Informatics and Logistics; Neuronic Engineering; Structural Biotechnology; Technology in Health Care.

The below organigram shows the KTH organizational structure. The number of faculty and the total number of employees are shown between brackets.



1.2. Structure of this document and focus areas for the experts

This short introduction is followed by the self-assessment of the two departments IS and MTH, and a short chapter outlining potential synergies between IS and MTH (optional – to be decided later).

The self-assessment is organized around six specific research aspects for each of the departments: (1) the overall analysis, strengths and development areas; (2) research profile; (3) viability; (4) organization and strategy; (5) interaction between research and teaching, and; (6) impact and engagement with society.

Aspects common for the entire department are addressed first. Thereafter, we address aspects that are specific for each of the divisions.

2. The Department of Intelligent Systems (IS)

A major university reorganization in 2018 reduced the number of KTH schools from nine to the current five. The current EECS school resulted from the merger of three previous schools (Electrical Engineering; Computer Science and Communication, and; Information and Communication Technology). In this process, the previous 16 divisions from all schools became grouped into four new large departments, of which Intelligent Systems (IS) is one. Three of the IS divisions (MST, ISE and DCS) came from the previous school of Electrical Engineering and have been in the same organizational constellation since the early 1990-ies; two of the divisions (RPL and TMH) came from the previous school of Computer Science and Communication.

The current constellation of IS crystalized early on during the school merger and was driven mainly by a common vision on research amongst the five divisions. Specifically, we believe that a strong focus on research excellence must form the base for all university activities (i.e., teaching, research and interaction with society). We further believe that a strong research environment in Sweden requires a substantial focus on raising external funding. This common understanding has allowed us to quickly establish a common culture within the IS department.

In EECS, all education related questions (incl. organization, economy, etc) and faculty recruitments are dealt with on department level. All research related questions (incl. organization, economy, etc) are dealt with on division level.

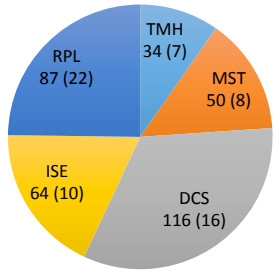
Section 2.1 below describes all aspects handled on the department level AND all research related aspects our divisions at IS have in common. Sections 2.2-2.6 describe the research aspects that are particular for each division.

2.1. The Department of Intelligent Systems (IS)

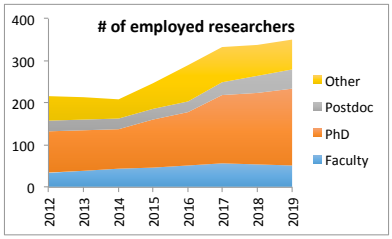
1. Overall analysis and conclusion; strengths and development areas

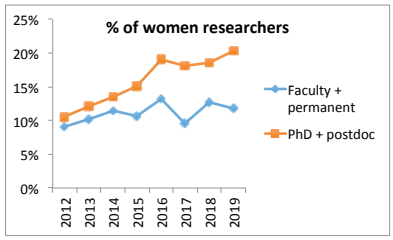
a. SWOT-analysis

Staff



Employees March 2020 / Total (women): Prof: 30 (2), Assoc Prof: 19 (3), Assist Prof: 4 (1), Adjunct faculty: 7 (0), Postdoc: 46 (8), PhD: 181 (46), Other: 64 (11)





12 of the 23 current assistant and associate professors did their PhD at KTH.

Strengths:

- Multidisciplinary faculty that covers broad research topics.
- Excellent researchers as proven by prestigious career awards: 2 “distinguished professors” granted by the national science foundation, 3 ERC Adv Grants, 3 ERC Consolidator Grants, 2 ERC starting grants, 2 Wallenberg scholars, 4 Wallenberg fellows,
- IS researchers are leading scientists in the community, as proven by membership in scientific societies: 7 IEEE fellows, 2 Royal Swedish Academy of Sciences (KVA), 2 Royal Swedish Academy of Engineering Sciences (IVA), 3 Young Academy of Sweden (SUA).
- Within every division, researchers have complementary expertise.
- High number of PhD students graduating, on average 0.43 per faculty member per year.
- Strongly increasing number of industrial PhD students (from none in 2012 to 26 in 2019), provide direct connection and collaboration with our industrial partners.

Weaknesses:

- Overall, very poor gender balance: The women/total faculty ratio is OK for RPL (5/13), very bad for MST (1/7), DCS (0/10), ISE (0/12) and TMH (0/11).
- The women faculty members excel scientifically (see bibliometry below) and IS therefore faces a substantial risk that they are headhunted.

Research profile

Strengths:

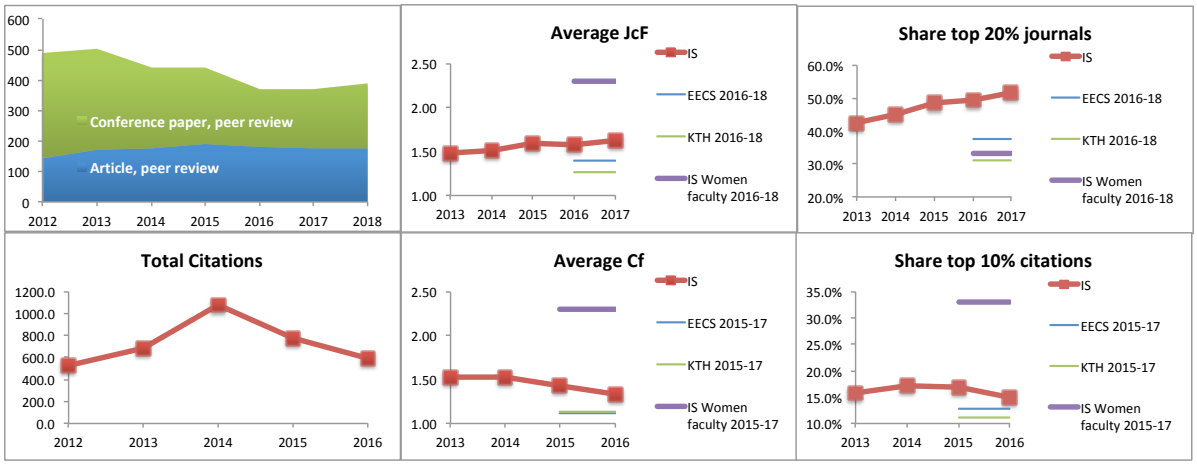
- Strong foundation in basic science opens up for contributions to new important applications.
- Important contributions to several application areas.
- We cover the topics within “intelligent systems” well.
- International visibility and recognition as evident by the large number of EU projects and involvement in the organization of most major conferences in our fields.

Weaknesses:

- Our broad research topic coverage leads to not reaching the full potential of scientific depth as gathering our resources around fewer topics might. We are aware of this, but given the Swedish research funding landscape, we still think our approach is best suited.
- Multidisciplinarity involves a risk in terms of compromising the depth of research.

- Where we focus on basic research, it is hard to "prove" societal and economic impact and sustainability. This is in disconcordance with external demands from KTH and funding bodies.

Publications record



Cf (field normalized citations) are normalized for WoS subject category, publication type and publication year. Jcf (Journal Cf) shows the average field normalized citations of the journals in which the unit of analysis has published.

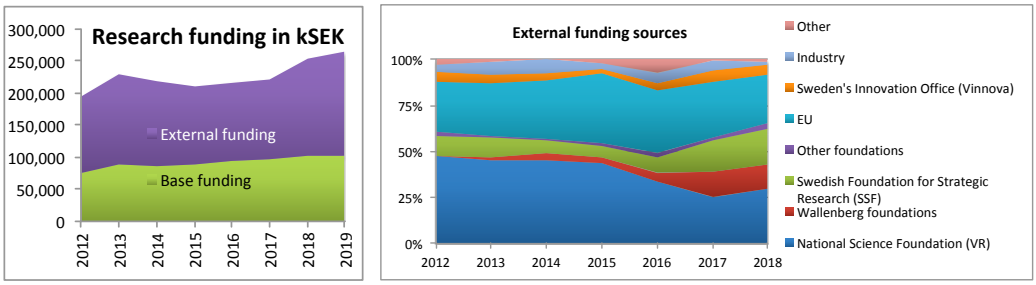
All key bibliometric performance indicators for IS are significantly better than those for the EECS school and for KTH in total. The six women faculty members perform best in most indicators, and excel specifically in publications in high-impact journals.

- Overall high publication volume, increasing number of peer reviewed journal publications (+20% during 2012-2018), decreasing number of peer reviewed conference publications (-37% during 2012-2018).
- Overall high publication impact (JcR and share in top 20% journals ~50% above field average), and increasing impact (+21% share in top 20% journals during 2013-2017);
- Many citations (~50% above field average);
- Presence at prestigious meetings and conferences.

Collaborations

- Cross-and multidisciplinary collaborations make us versatile and adaptable to create new research areas and creatively tackle new challenges.
- Large national and international network in academia and industry.
- Strong record in spinoff companies (19 during 2012-2019) and collaboration with companies.

Funding



Strengths:

- Strong and increasing external funding (+35% during 2012-2019)
- Strong funding for both basic and applied research, and from a wide range of sources.

- Most faculty members have been successful in attracting substantial external funding.

Weaknesses:

- External funding is often not given to entirely new research directions. Our strong dependence on external funding limits our ability to take substantial risks in the pursuit of new topics.
- When large funding is secured, it is typically spread wide, reducing risk but at the same time possible impact.

Recruitment

Strengths:

- Increasing number of female PhD and postdoc students (+83% during 2012-2019);
- All recruitment is in competition and we typically have a large number of candidates applying.
- Of the 12 centrally-funded assistant professor positions, 3 are at IS (Herland, Leite and Tumova) and all three are women! This is a good example of why we need to have very broad recruitment announcements so that we can draw from a much larger source of women than what is the case when we have narrowly defined faculty position announcements.

Weaknesses:

- Very few women apply for faculty positions.

Internal cooperation

- IS researchers are/were in leadership positions within KTH (Digitalization platform, Life Science Technologies)
- IS researchers lead major national initiatives (ICT-TNG, WASP, Digital Futures).
- All divisions have projects with other divisions within the IS department, EECS school and university-wide.

University ranking (important to attract excellent students and faculty)

Strength:

The fields covered by the department are traditionally categorized as electrical engineering (EE), a subject area where KTH was ranked as the 17th best university worldwide at QS. EE is the highest ranked subject at KTH.

Weakness:

Overall, KTH drops in the university ranking. Even more worrisome is that there are no targets set and no significant contingency actions taken.

Organization

Strengths of IS departmental organization:

- Flat organization with clear and distributed responsibilities and strong anchoring of important decisions; collegiality, transparency, positive spirit.
- A common view on research culture/values/principles, for example on research excellence being the base of research, teaching as well as interaction with society.
- Each faculty member explores his/her own research ideas.

Weakness in the EECS school level and KTH university organization

- Decreased focus on, and no significant incentives for, research excellence (cf. decline in university ranking vs. no targets and no significant contingency actions).

- Too lengthy faculty recruitment procedures, in which good candidates disappear. This undermines long-term research excellence.
- EECS decided that faculty recruitment should be primarily based on teaching needs rather than research excellence. This undermines long-term research excellence.
- In terms of evaluation for promotion, the required quality of research excellence is too low (e.g., very limited demands on external research funding). This undermines long-term research excellence.
- No mechanisms address low research performance for individual senior faculty members.
- There is an increased number of teaching administration positions, now on all levels (division, department and school). The purpose of these tasks often seems to make sure that KTH can say that we have processes in place rather than actually caring about quality. These tasks consume time but lead to limited improvements in teaching/research quality. We would benefit from more trust, less administration. At the same time, a track record in such positions is a prerequisite for promotion.
- Wrt collegial structure: Swedish universities are top-down steered by a President appointed by the government. At the same time, forums for critical and independent academic debate and communication within KTH have diminished in the past two years. (E.g., the previously independent KTH Faculty Council has become incorporated within the KTH line organisation; the independent KTH internal newspaper "Campi" was discontinued.) This *de facto* weakens anchoring of leadership decisions and undermines collegiality.
- At KTH level, strong research leaders do not take on academic leadership position often enough. This is unlike many highly ranked universities.
- Administration is costly, specifically in comparison with other academic institutes in Sweden. This is financed through a high OH (~50%) on research activities. Researchers, however, are neither in control over those costs, nor over the size and activities of the central research support administration.
- A more centralized KTH organization has been enforced with a one-model-suits-all (?) organization and administration ("One KTH"). This results in a less efficient administration for our department. At the same time, we have not seen that benefits would outweigh the costs for our department. For MST, DCS and ISE, the OH has increased because the former EES school had a much leaner organization.
- Cautious and bureaucratic administration - without an own stake in the results - make up new praxis, without beneficiaries, and at increased costs for research. This is a systemic problem rooted partly in the KTH administration being its own organization separated from the core research and teaching activities.
- KTH, and specifically the president, advocates a strong focus on sustainable development and gender equality. The KTH organizational structure is geared towards these goals, each having their own vice president and administrative staff. However, the realization on the department/division level remains limited, due to lack of significant (economic) incentives (such as results-based internal fund distribution schemes). The result is a continued gender imbalance and an increasing climate impact of the university itself.

Important future development areas:

Wrt research excellence, we suggest:

- Stronger incentives for research excellence (financial rewards and/or conditions for promotion).
- The drop in university ranking can only be addressed by moving resources to the best research environments. Strong environments foster new strong researchers and new strong research areas.
- On a school and university level, clearer expectations, and related incentives, on raising external funding by faculty members (financial rewards and/or conditions for promotion). E.g., only 5% of the total EECS faculty apply for ERC grants.

Wrt gender equality, sustainability, impact and internationalisation: significant improvements in these areas require that the KTH leadership generates relevant and significant incentives for the departments, divisions or individual researchers.

To reach the government target for gender balance at KTH, which is set at 32%, we suggest implementing proactive financial incentives:

- Doubled financial starting packages for women faculty.
- We request that the KTH leadership puts a *serious* investigation to address the "two-body problem", i.e., costs related to, or the lack of attractive career possibilities for, moving spouses.

Wrt administration, we suggest:

- a tighter integration of administrative support within the divisions where administrative persons (and not anonymous "functions") have good understanding of actual needs.
- an organisational model where researchers have control over the costs, size and activities of administrative research support units.
- a targeted cap on OH, also at KTH level.
- not allowing new administrative regulations or change of praxis, unless they are either proven beneficial to either students or teachers, or triggered by **recent** changes in laws or state regulations. The aim must be that if something is added, it is compensated for by removing something else so that the administrative burden does not grow unbounded.

b. Summary statement on contributions of the IS department on impact, infrastructure and sustainable development

IMPACT: We believe our impact is relatively high, see sections 6a, b and e. Our outreach can be further improved, however, and efforts are ongoing to train PhD students and set up work flows to engage more people. The importance is that skills for outreach align with aiming at publishing in higher impact journals. We thus believe that efforts towards more outreach will also lead to more citations and better university ranking.

Infrastructure: We have good, and in many ways unique, lab environments. Care must be taken, though, that these environments are maintained and supported financially where necessary. Details are described in section 3e.

Sustainable development: We develop key technologies that contribute in various ways to addressing the Grand Challenges of society. However, our research has often focused on challenges in Sweden and Europe, which means we typically address questions that might become targets for the 2050 rather than the 2030 UN agenda. Details are described in section 6c.

2. Research profile

The research at IS includes the following topics:

@MST: Microsystems (MEMS) and Nanoengineering (NEMS) and their application in the fields of medicine, life sciences, information and communication technology (ICT), security, transport, and aerospace.

@DCS: modeling, identification, control, learning and optimization of dynamical systems.

@RPL: robotics, computer vision and perception in general, and machine learning and their application in areas such as production and transportation systems and medicine.

@ISE: digital communication and networking, signal processing and data sensing, multimedia processing, and the utilization of stored and real-time data for information extraction and predictions.

@TMH: communication and interaction between humans via speech and music. The department is engaged in a diverse set of multi-disciplinary research activities, with the main areas being speech communication, speech technology, multimodal interaction technologies, voice science and technical vocology, music informatics, and auditory perception.

All other aspects related to the research profile are addressed per division.

3. Viability

a. funding

In short, we have high and increasing funding both for basic and applied research. For our current funding and its evolution, see data in the SWOT analysis under point 1a. In short, we have high and increasing funding, both for basic and applied research.

Allocation of faculty funding at KTH depends to some degree (0.3%) on bibliography

This is a small amount, but its impact comes from the prestige related to it.

Allocation of faculty funding depends strongly on the amount of external funding raised – on a school level. This is needed to handle the high requirement for co-funding due to the high OH.

Further details are provided per Division.

b. Academic culture

See under Divisions.

c. Current faculty situation

For our current staffing and its evolution, see data in the SWOT analysis under point 1a. Details are provided on a per-division level.

The academic positions at KTH are affiliated to the internationally established concept of Tenure Track. The Tenure Track starts with a post as assistant professor, for which a PhD and postdoctoral experience are required. After approximately four years, an assistant professor has the right to be considered for promotion to associate professor, and if this is successful, to be permanently employed. After a further period as an associate professor you can apply for being promoted to professor. Faculty members either leave out of free will (e.g. new offers) or via retirement. It is uncommon to lay off faculty members.

An assessment of IS in 2018 shows that, given no new faculty would enter and none would leave out of free will, the current faculty would evolve as shown in the table below.

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Prof (female)	27 (2)	32 (2)	34 (2)	37 (2)	40 (3)	41 (3)	41 (3)	42 (4)	43 (5)	44 (5)
Assoc Prof (female)	20 (2)	15 (2)	16 (3)	14 (4)	12 (3)	12 (3)	7 (3)	6 (2)	5 (1)	4 (1)
Assist Prof (female)	6 (2)	6 (2)	3 (1)	1 (0)	-	-	-	-	-	-

d. Recruitment strategies

Recruitment of faculty is performed on a department level (but controlled to a large extent by the divisions); recruitment of PhD students and postdocs is done on a division level.

For Faculty:

Assuming a steady-state faculty size and considering demographics, we can expect the need to recruit on average 1.5-2 new faculty members per year in a long-term perspective. The current EECS school stipulates that "*Faculty recruitment should be driven by the teaching needs of our programs within the context of our departments*". In 2018, IS made a teaching need analysis, wrote a IS faculty development plan and planned the following 10 recruitments during period 2018-2023:

- One assist. prof. in Intelligent Systems with specialization in Social Science.
- Two positions in Autonomous Systems and Software. (1 in progress)
- One assist. prof. position in real-time decision and control systems.
- Two assist. prof. in Intelligent Systems with specialization in Machine Learning. (1 already in place, 1 in progress)
- One assist. prof. in Intelligent Systems with specialization in Artificial Intelligence.
- At least two assist. prof. in Intelligent Systems with specialization in Speech Technology.
- One assist. prof. in Intelligent Systems in Lifesciences / Health.

New areas that could be added (i.e. as a 2020 update to our 2018 plan):

- Quantum information theory
- Other…

Gender balance in faculty recruitment:

The preparation of this document actualized that the leadership has not succeeded in improving gender balance at faculty level for over 20 years. The following steps should be implemented:

- **Broad recruitment calls:** To attract diverse faculty candidates we should recruit with a broad focus and for many positions simultaneously, and not go for smaller targeted recruitments with narrowly targeted topics. Besides addressing gender diversity issues, this may lead to establishing new research directions previously not considered.
- **Addressing the two-body problem:** An important aspect, which has occurred four times during the past years, is the "two-body problem", in which women that are offered a faculty position do not accept because their spouse does not find an attractive workplace. (The opposite has never occurred.) We want to increase pressure on the KTH leadership to free financial support to specifically address the two-body problem. We believe it is crucial that KTH creatively investigates different options to address this problem. Similar solutions exist, e.g., for family relocation in European MSCA scholarships.

- **Starting packages for recruits that improve diversity:** We decided in March 2020 to double the "starting package" for newly recruited women faculty. Other financial incentives should be investigated.
- **Re-open the discussion, rely on new intelligence, put new practice / incentives in place:** The discussion on how to tackle the gender imbalance must be reopened. Previous discussions among the current leadership typically strand on the conviction that the Swedish law (not allowing to favour based on gender) and the fact that we must choose the best-suited candidate in a group prevents improving this situation. We must find ways to circumvent this stalemate and need new thinking by new people. **As a result of this evaluation, we have now started such a process within our school.**

Recruitment of PhD students and postdocs

Recruitment of PhD students and postdocs occurs on a per-division level, and praxis varies between the divisions (as described on the per-division level). Divisions seem pleased with the quality of students they recruit and they perceive that they make efforts to address gender diversity. This has led to a "*if it ain't broke don't fix it*" attitude that has stopped the division leaders from considering broader recruitment committees for PhD or postdoc students, which could improve the diversity, and perhaps quality, of our recruits. The leadership will remain very skeptical to such changes unless there would be proof that changes would improve the quality of recruits.

Scholarships vs employment for postdocs:

Recruitment happens always in open competition. KTH regulations make it increasingly hard to accept students funded by either external or internal scholarships, instead enforcing a 2-3 times more expensive employment. Students that would come on (too) low scholarship are not allowed, but at the same time we are not allowed to top up their scholarships with extra funding. As a result, PhD and postdocs at KTH are significantly more expensive than in other countries and many potential students *that come with their own scholarship funding* are denied an education opportunity. If KTH were to address this systemic problem by proactively investigating win-win solutions for such HR problems, rather than proactively searching for potential legal boundaries (you can always find those if you search hard enough), this would result in increased knowledge creation and an increased influx of highly-skilled persons to the country.

e. Infrastructure and facilities

MST infrastructure for MEMS/NEMS fabrication and research translation

Current status: We have several well-equipped in-house lab infrastructure:

- Polymer microsystems lab
- RF/THz lab
- Photonics lab
- 3D nanostructuring lab (micro 3D-printing, 3D laser micro- and nanomachining),
- Cell & microbiology facilities.

We work in other major infrastructures, including:

- Electrum Lab and Albanova Nanofabrication Facility (www.myfab.se/KTHRISE.aspx) = KTH node of the Swedish research infrastructure for micro- and nanofabrication. These cleanroom environments are the most crucial research infrastructure for MST.
- Scilifelab (www.scilifelab.se) = National hub for molecular biosciences.

- MedTechLabs (www.medtechlabs.se) = Regional interdisciplinary centre for medical technology research.
- Biomedicum (ki.se/en/about/biomedicum-a-laboratory-of-the-future) = Experimental research centre of the Karolinska Institute.

Development of infrastructure: we are proactive in the procurement of new tools and instrumentation, especially for the Electrum Lab and the Albanova Nanofabrication Facility.
Assessment (strength/weakness): One of our strength is the access to a variety of micro and nano-manufacturing tools and competences at KTH and MST. A disadvantage is that these type of tools and lab facilities are comparably expensive and underfunded. Continued central support for the Electrum Lab and Albanova Nanofabrication Facility is paramount for our research area…

DCS infrastructure:

Integrated Transport Research Lab (ITRL) https://www.itrl.kth.se/

Smart Mobility Lab (Jonas, Dimos, Kalle, …)

Digital futures (Kalle)

RPL infrastructure for robotics and computing:
Current status: We have several well-equipped in-house labs

- The largest lab contains among other things 3 Yumi ABB robots, 2 Franka arms, 1 PR2 dual arm mobile robot with, 1 Clearpath Ridgeback mobile robot with a Baxter dual arm mounted on it, an ATRV2 outdoor platform and a wide variety of sensors.
- A drone lab with a cage protected by nets for early testing, equipped with a 16 camera MoCap setup for positioning. We have access to a large set of off the shelf and custom-built drones, from nanodrones (Crazyflie) to > 1 m diameter outdoor drones.
- A social robots lab with five Nao humanoid robots and a Pepper robot (wheeled) as well as a large number of smaller robots and sensors.
- We have a GPU server in-house with 38 GPUs.

Development of infrastructure: We have just ordered a 1MSEK upgrade of the GPU resources (38 to 58 GPUs). Robotics equipment is typically connected to projects and updated in connection with these.

Assessment (strength/weakness): The main weakness is the lack of research engineers to maintain the robotics facilities. This means that PhD students have to do a lot of the work, which means that they spend time on engineering instead of research and that much of the knowledge is lost when someone leaves. This has always been a challenge and we have managed to stay competitive. However, as robotics evolves to become more theoretical, students will have less time for practical work. We see this as a major challenge for the future. One of the initiatives to counter this, is the idea of establishing a so-called Robotics Concept Lab. Its aim is to reduce the gap between the research done at RPL and in industry. The vision is that the lab would employ a handful of senior research engineers, similar to for example the Oxford Robotics Institute.

ISE infrastructure:

Current status: Relatively little infrastructure is needed in our field. We have smaller infrastructure, including universal software radio peripherals (USRPs) and a small electronics labs.

Development of infrastructure: One piece of infrastructure that is of increasing importance is the computational resources required for data-driven machine learning. The division has made investments in local computations resources, both for CPU based calculations as well as GPU based calculations. An example of the latter is the purchase of an Nvidia DGX Station. The division, like any other division at KTH and in Sweden, has access to national resources such as the PDC Center for High-Performance Computing, and efforts are made nationally to expand the GPU computation capabilities of this resource as well as expanding its capabilities from batch-jobs to interactive prototyping of data-driven methods.

Assessment (strength/weakness): It is currently unclear what the right balance between investments in local computational resources versus reliance on national infrastructure is. Finally, one perceived lack of needed infrastructure is the availability of affordable archival storage of data from simulations and measurement campaigns as well as raw video data captured for producing online lectures.

TMH infrastructure:

Current status: We have several well-equipped in-house labs

- Språkbanken Tal is part of the *Nationella språkbanken* (National Language Bank) that in 2018 was funded by the Swedish Science Council's programme for *research infrastructure of national interest.* The initial funding for the infrastructure runs over 7 years, over which the KTH share is in excess of 22 MSEK. Through Språkbanken Tal, KTH is the National Coordinator for the European Language Grid (ELG), that focus on infrastructure that is available to the industry. Språkbanken Tal has achieved funding for several supporting infrastructure projects, including 8 MSEK from RJ for developing ASR for audiovisual collections of the National Library, 6 MSEK from Vinnova for developing Swedish speech synthesis for long and information rich texts, and 4 MSEK from PTS for developing a speech technology that makes lectures more accessible.
- We have three recording studios for audio recordings: a large studio used in both research and teaching, a smaller studio that is used by Språkbanken Tal, and a recording pod placed in our interaction lab, to allow for daily dialogue recordings.
- We have a large motion capture lab, the Performance and Multimodal Interaction Lab (PMIL). It is a multi-purpose facility for data collection and experiments in multimodal interaction. It currently features a 20 camera motion capture system (including 3 frame synchronized RGB cameras), 3 head mounted gaze trackers, VR equipment and sound recording equipment.
- We have a GPU server in-house that is in the process of being expanded from 16 GPUs to 40 GPUs.

Development of infrastructure: Together with RPL we plan to build the Robotics and Interaction Labs, KTH IRL, at LV24 when the space becomes available in 2022. Apart from moving RPL's existing robotics labs and PMIL to our shared premises, we will build a smart home lab for user trials robots and speech assistants for assistive living.

Assessment (strength/weakness): The main weakness is the lack of research engineers. The strength is our involvement in society, where Språkbanken Tal will have an increasing role.

4. Strategies and organization

a. Goals for development 5–10 years ahead

See under Divisions

b. Congruence with university-level goals for research as set out in "A leading KTH - Development Plan 2018-23" and with the school development plan.

Our research is congruent with university level goals in the sense that: it addresses to a large degree digitalization and sustainability; we do basic and curiosity-driven research, as well as applied and industry-related research; our bibliometric data shows the high quality of our research; we consider ourselves internationally competitive (cf. our QS topical ranking); we increasingly involve adjunct faculty, and; we often work in large projects with several actors.

The IS faculty wrote its own school development plan during 2018, and our research is still largely in line with those plans.

c. Leadership structure and collegial structure on the Department level

IS has biweekly management meetings, including the Head and Deputy Head of department and the 5 Division Heads (or their Deputy). The Head of Teaching at IS is automatically Deputy Head of the department. We plan annual Faculty Days to foster cross-division faculty collegiality.

d. Strategies for quality

Research quality is at the core of everything we do. This culture is supported by the continuous discussion of this topic on all levels within IS.

Each division at IS has its own strategy for publication (see division level).

Our bibliographic and ranking data is compiled yearly on a KTH level, and we follow these data points closely.

Allocation of faculty funding depends to some degree (0.3%) on bibliography and to a substantial degree on the amount of external funding raised, which works as incentive. See section 3a for details.

5. Interaction between research and teaching

When teaching ***fundamental courses*** **at Bachelor's and Master's level**, motivating examples from our current research projects provide students with new insights and create curiosity. Students are exposed to the culture of our research community for the first time, and the research community will benefit from these well-trained and curious students in the longer run.

As the students progress, ***advanced courses*** **at Master's level** provide students with specialized training based on current needs of the research community and opportunities to dive deeper into current research questions. These courses are to a large extent connected to and inspired by our core topics of research.

First hand-on experiences are gained in our ***project courses*** **both at Bachelor's and Master's level**. Students work for the first time independently on small research projects typically provided by our PhD students and postdocs, and gain maturity before the final degree projects.

In their **final *degree projects***, the students work independently on real research problems, either in industry or at KTH. In many cases, students who have shown excellent research performances in their degree project, are likely to be recruited by us as PhD students.

At PhD level, our courses are entirely tailored to the research needs of our students and teach important theoretical concepts that we believe are essential for the success of our PhD students. PhD courses are continuously updated, reinvented, and created from scratch. Compulsory courses on research ethics, methodology, and sustainability complement the skills of our students. All this provides ISE with good opportunities for interaction between research and education.

6. Impact and engagement in society

To increase the logic in the narrative, we describe in the following order: our overall approach/strategy to reach impact (e); our relevance and interaction with stakeholders and society at large (a); our dissemination activities (b); examples of impact cases (d), and finally; how we address the UN sustainability goals (c).

e. Our main mechanisms to reach impact are:

1. Through people:

- Our students that end up in industry are perhaps our largest impact on society.
- Industrial master thesis students, industrial PhDs, affiliated and adjunct faculty

Examples:

From MST: Of the 36 doctoral graduated since 1996: 22 are now in industry of which 4 are CEO or partner, and; 12 are in academia, of which 6 are professors and 3 assoc. professors.

From ISE: See impact ISE impact case 1.

2. By bringing methods and products to use:

- Via collaborations with stakeholders in industry and society (see 6a)
- Via IP: We had 24 approved patents during 2012-2019.
- Via commercial spin-off efforts (19 during 2012-19), e.g.:
  - **@ MST:** Mercene Labs, Capitainer, Zedna, Grein Research, and CellectEve. For more information, see https://www.kth.se/mst/spin-offs-1.447465
  - **@ RPL:** Gleechi, Volumental, Vantagist, DeepMed, DermAI, InfoBrain, Fellowbot, 9tails. For more information see https://www.kth.se/rpl/spin-offs-1.966268.
  - **@ ISE:** R3 - Reliable Realtime Radio Communications GmbH. For more details: see impact cases under ISE.
  - @ TMH: Furhat Robotics

  Other ?: Modern Ancient Instruments Networked AB; Deep Edge AB; Appalanche AB,; SynFace AB,; WEMEMOVE AB; Monocular AB:

3. Via engagement in advisory boards / industrial boards / learned societies:

IS staff is engaged in society and industry as representatives in many boards. Highlights include board membership at SAAB, H&M, Wallenberg's holding company FAM, the Swedish Research Council, Swedish Foundation for Strategic Research and membership of the Royal Academy of Sciences, the Royal Academy of Engineering Sciences. More details on personal engagement can be found on the profile pages of individuals, which can be found via the "contact" or "staff" entries on the department or division websites.

4. Impact via dissemination: (See 6b).

5. Proactive developments to increase impact: on the EECS school level, two "impact leaders" work to support and increase research impact. Activities include:

- A school research communication plan, based on current praxis at MST, will streamline communication of research results (accepted journal papers) to key stakeholders and society at large (via traditional and social media).
- The hands-on PhD course "From research to Impact" (www.kth.se/social/group/feo3120-from-researc) trains PhD students in moving ahead on the technology readiness ladder and in research communication.
- A communication tour of central research, communication and innovation support units at KTH to all divisions to relay what service they can provide and receive feedback from researchers.
- Impact leaders will encourage researchers to apply for internal and external funding for outwards person mobility (academics to industry) and investigate incentives to this end.
- Impact leaders will review master thesis projects and their impact (# of theses performed with industry, # of patents, etc.) and analyze for potential improvements wrt creating impact.

a. Relevance of research

Relevance to society at large:

Our research results are relevant to society in a multitude of ways.
Research at MST aims at applications in medicine, life sciences, information and communication technology (ICT), security, transport, and aerospace.
Research at ISE has direct impact on applications in wireless systems, cyber-physical systems, multimedia, smart green and integrated transport and cities, electric power systems, biology and health.
Research at DCS has direct impact on applications in autonomous systems, networked systems, process control, robotics and secure systems.
Research at RPL focuses on robotic systems that provide advanced service in industry, for search and rescue operations, in medical applications or as assistants to elderly.
Research at TMH aims at multimodal human-computer interaction systems in which speech, music, sound and gestures combine to create human-like communication.

Relevance for specific stakeholders:

We work with hundreds of industrial and societal stakeholders. Amongst our most important ones are:
@ MST: Medical practitioners/Region Stockholm, SHL group, SenseAir, Mycronics, Silex Microsystems, Huawei. For more examples,
see https://www.kth.se/mst/research/external-partners-1.58117.
@ ISE: the Swedish Civil Contingencies Agency, Ericsson, Scania, SAAB, ABB. For a more

complete list, see https://www.kth.se/ise/research/research-collaborations-1.965234.
@ RPL: Scania, ABB, Tobii, Univrses, Toshiba. For a more complete list, see https://www.kth.se/rpl/external-partners-1.966277.
@ DCS: Scania AB
@ TMH: PTS

Gender aspects in our research topics:

Several projects focus on health issues most prevalent in women, including: research on urinary tract infection diagnosis (MST), breast cancer (RPL) and tissue models for Alzheimer Disease (MST).

Joint positions between academia and society

We currently have 23 industrial PhD students: 11 at RPL, 2 at MST, 4 at ISE

Adjunct faculty: In line with the KTH strategy, we have an increasing number of adjunct faculty.

ISE hosts one affiliated faculty (employed by ABB) and one adjunct professor (employed by Ericsson).

The largest fraction of our master theses is performed in collaboration with industry.

b. Research dissemination beyond academia

Several faculty members have received widespread visibility via national media (newspapers, TV, radio), social media, etc. For examples of dissemination to a broader audience, see:

- For MST: https://www.kth.se/mst/news
- For RPL: https://www.kth.se/rpl/rpl-news

Some researchers have a proactive strategy for communicating research results, typically in conjunction with journal publications. Channels that can be systematically targeted are:

- KTH news website
- Specific news releases
- Wikipedia
- Social media, where specifically LinkedIn, Facebook and Instagram allow targeting specific channels.

However, most researchers do not follow a systematic approach in this. We hope that the school research communication plan (see section 6e point 5) will help remedying this.

Furthermore, to visualize impact of research communication to researchers and instigate an increased effort, we suggest KTH to systematically track and report the Altmetric score of all publications (https://en.wikipedia.org/wiki/Altmetric).

c. Sustainability and the United Nations' Sustainable Development Goals (SDG)

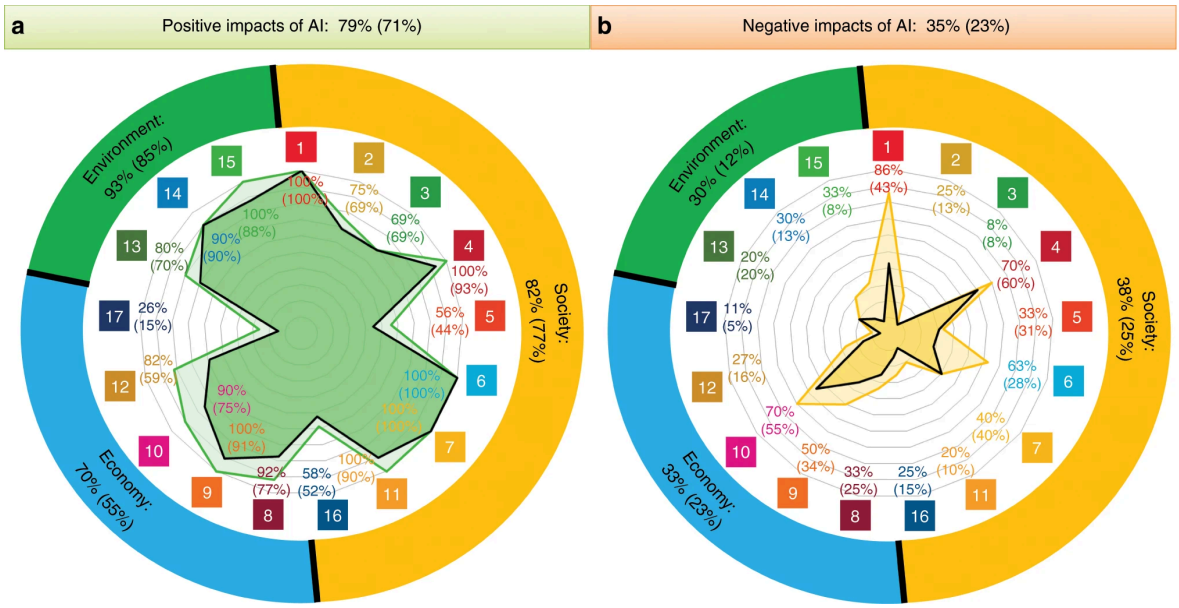
The KTH tool to correlate our publications with sustainability goals does not provide relevant results and its results should be disregarded.

We develop key technologies that contribute in various ways to addressing the Grand Challenges of society. **Our theoretical and basic research** provides key technologies in our core research areas. While we often pride ourselves to validate our research on real world platforms / environments, with much of the research being foundational rather than application-driven. Reflecting further on how our basic research can be used for sustainability does not seem meaningful as it would be highly speculative. Much of **the**

applied research we conduct is done in collaboration with companies and healthcare. In this research the focus is on challenges in Sweden and Europe. This means addressing questions that might become targets for the 2050 rather than the 2030 agenda.

Addressing the question of how much of the research is related to sustainable development is difficult. Close to 100% of the research is relevant through enabling technologies, but close to 0% is directly addressing the SDG targets.

A large part of the research at IS focuses on AI-related technologies. Our article "The role of artificial intelligence in achieving the Sustainable Development Goals", ***Nature Communications*** 11, 233 (2020), co-authored by faculty from RPL, shows the positive and negative impact of AI on the various SDGs.



Examples of more applied and targeted work towards sustainable development include: **@ MST:** Our micro- and nanostructures and sensors form a base for (1) better medicine; (2) the "other side" of the IoT; (3) automation in industry and transport, and; (4) environmental sensing and monitoring. We address:

- SDG3: Roughly half of MSTs research is life science and medicine related, with specific focus on basic disease mechanisms and therapy of infectious diseases (target 3.3), cancer (target 3.4), and diseases of the nervous system. SDG targets focus mainly on health for developing countries, whereas our work addresses disease in the developed countries. We directly address target 3.4.1 (Reduce mortality cancer, diabetes or chronic respiratory disease); other targets are addressed *indirectly*.
- SDG 9: We have several projects on beyond-5G telecommunication, all in the sub-THz frequency spectrum, in particular on high-data rate point-to-point communication networks for future network infrastructure. We have several remote-sensing projects exploiting THz frequencies, including a national project on space-borne earth observation environmental sensors.
- Target 11.2: We have several projects on sub-THz radar sensors for road safety, including traditional car radar but also emerging radar applications such as in-cabin monitoring and critical-road crossings surveillance.
- SDG X: Photonic CO_2 sensors for environmental sensing and monitoring.

@ DCS: improving energy-efficiency in society. In addition to this broader perspective, the faculty is running several projects on smart grids, energy-efficient communications and computations, smart transport, and healthcare, to mention a few.

@ RPL: robotics, perception and learning, for a sustainable future.

- SDG 3: Our research on breast cancer addresses UN SD goal 3. The current targets for this goal are focusing mostly on third world diseases and health issues. However, in large parts of the world cancer is one of the main causes of death.
- SDG 14: Better utilization of the oceans for food and energy are goals in the project SMaRC. By automating the monitoring of Algae farms one can produce more while using fewer resources. Better georeferencing oceanographic measurements by correcting navigation using sonar will make that data of better quality for modeling the processes of global warming.

d. Impact cases

Below are 10 impact cases:

- ISE Impact case 1: Provisioning telecommunication industry with highly trained people
- ISE Impact case 2: Research collaborations with KTH strategic partner Ericsson
- ISE Impact case 3: Start-up R3 Communications
- ISE Impact case 4: The Mabtech IRIS
- ISE Impact case 5: Expert Advice to Public Sector
- TMH Impact case 6: Furhat
- MST Impact case 7?:
- RPL Impact case 7-9
- DCS Impact case 10

ISE Impact case 1: Provisioning telecommunication industry with highly trained people

The Division has had a strong impact on the telecommunication industry by providing it with highly skilled staff both on undergraduate and graduate level but also post-doc researchers for several decades. The relevance and quality of the training become visible from the fact that a large portion (58 %) of the PhD graduates of the division continue to work in the telecommunication industry, while most of the other graduates continue their research in post-doc positions.

Total number of PhD graduates of the Division 2010-19	Now with Ericsson	Now with Huawei	Now with Nokia	Other telecom. related industry
59	26	3	2	3

ISE Impact case 2: Research collaborations with KTH strategic partner Ericsson

There exist close relations between Ericsson and the Division of Information Science and Engineering. Mikael Skoglund is KTH's strategic partner contact for Ericsson. The division has been the host for two adjunct professors from Ericsson (Ulf Forssén 2014-18 and Bo Göransson since 2019). In several research projects the division collaborated with Ericsson, including high profile European collaborative projects such as EC projects QUASAR and METIS where the division contributed to the development of the 5G mobile standard 5G.

All these collaborative efforts contributed in various degrees to Ericsson's effort to standardize, develop, prototype and commercialize its product portfolio in the domain of 5G network equipment. Recently, Ericsson started to accept industry PhD students. The faculties of the division act as academic supervisor for three students working funded by the WASP and SSF industrial PhD student programs.

ISE Impact case 3: Start-up R3 Communications

Efficient industrial automation depends on effective communication between distributed automation equipment for autonomous coordination. For decades this relied on cable-based systems. However, market pressure demands from automation equipment more and more flexibility. Such flexibility can only be provided through wireless access. Research over the last decade has been pioneering principles that can provide enough reliability even in harsh industrial automation environments. After validation, the research has lead to several IP families, which are today the foundation of a start-up company R3 Communications in July 2015, commercializing the IP in several different markets with global players in the industrial automation market. Since then R3 has grown into a Venture-Capital backed company with a size of 25 full-time employees. R3 collaborates with several global players as lead customers in the industrial automation sector, and is collaborating with Texas Instruments with respect to wireless system integration. R3 won the "Fog Tank Award '' and 1st Prize of the Global IoT Finale of the 2nd China Innovation & Entrepreneurship International Competition in 2018 and the Deep Tech Award of Berlin in 2015.

ISE Impact case 4: The Mabtech IRIS

Stockholm based biotech firm Mabtech AB contacted our researchers to initiate a discussion about analysis methods for a type of biomedical assays called ELISpot and Fluorospot. The discussion led to a one-year research project at KTH, with direct industry funding from Mabtech. The project resulted in a new analysis method based on novel physics-based modeling of the assays and a solution based on optimization in function spaces. The performance of the new method improved upon state of the art in the field to the extent that Mabtech, through a joint venture with the Swedish high-tech consultancy company Qamcom, developed an entirely new product -- the Mabtech IRIS -- based on the results. The product launched in 2018, a mere three years following the start of the initial project, and a marked expansion of Mabtech's product portfolio from monoclonal antibodies (biology) to assay analysis machines (electrical engineering). One of the first use cases of the IRIS, a malaria study in Kenya, was recently published in the Journal of Immunological Methods. This case study, therefore, also provides an example of how fundamental research developed at KTH acted as an enabler for solutions to the sustainable development goals (SDGs), in this particular case SDG 3.3 and the eradication of infectious diseases such as malaria. See www.mabtech.com/iris.

ISE Impact case 5: Expert Advice to Public Sector

ISE has a strong impact on the society at large by engaging in a number of collaborations with partners from the public sector, like Region Stockholm, the City of Stockholm, Karolinska Institutet, the Swedish Civil Contingency Agency MSB, the Swedish Defence Research Agency FOI, Swedish Data Protection Boards, Swedish Energy Agency, and Trafikverket. Explicit examples are listed below.

- A study on Digitization of Health Care in the Region Stockholm in 2018, to which we contributed with our expertise in wireless security. The study was carried out in close collaboration with the Head of Innovation at Region Stockholm and helped the Region Stockholm to create awareness and a better understanding of vulnerabilities.
- Contribution to the planning of a Health Data Center of Region Stockholm with expert advice on privacy risks in several dedicated meetings with Region Stockholm leadership and experts from Karolinska Hospital and significant contribution to KTH response report on Region Stockholms referral on this issue.
- A survey on recent results and trends in information security research at KTH, carried out for FOI in 2017.
- The Swedish Energy Agency identified the issue of smart meter privacy after our outreach and included integrity in their research program. In our research project STOMP we develop strategies to enhance privacy.
- Several studies on cyber security for railway systems have been carried out for the Swedish Transport Administration Trafikverket.
- Joint work with the faculty driven startup Movelo AB to develop an app based insurance telematics solution for drivers insurance.
- ISE faculty members are also part of further collaborations with the Swedish Transport Administration Trafikverket through European Project Shift2Rail which eventually will help Trafikverket to overcome the current shortage of highly qualified workforce by providing the railway sector with 2-4 well-trained PhDs.

TMH Impact case 6: Conversational Social Robotics

Summary of the Impact

Robots that can interact with humans in a social way using spoken natural language, facial expression and eye gaze have applications in a wide range of areas - education, service, retail, health, elderly care, simulation, training and entertainment. Research from KTH and ICTTNG is now enabling this transformation worldwide: Deutsche Bahn is currently deploying social robots as information guides in airports and train stations in Germany and Japan to guide passengers in. Swedish recruitment agency TNG is pioneeri ng an unbiased recruitment process where candidates are being interviewed by a robot that is inherently agnostic to gender and ethnicity. MERCK is developing health screening robots to detect underdiagnosed diseases. Bandai Namco is exploring roboticized versions of their computer game characters to serve as greeters at theme parks. All of the above based on technologies originating from KTH Department of Speech, Music and Hearing by Prof. Beskow, Prof. Skantze and colleagues, since 2010 supported by the ICT TNG environment.

Research Area Background

During recent years, we have witnessed the start of a revolution in personal robotics. But as robots are entering human domains, there is a need for robots that are able to interact with humans in a socially intelligent way, using spoken language as well as non-verbal cues that humans intuitively understand. This research inherently interdisciplinary line of research encompasses robotics, natural language processing, dialogue modelling, non-verbal behavior, speech technology and more. Speech-only devices have already taken center stage in human machine interaction with massive proliferation of smart speakers and virtual assistants. Conversational social robots take the interaction paradigm one step further and aim to include all the cues and channels that humans use in face-to-face communication, which opens up for a large array of new application domains. The

European Strategic Research Agenda on Robotics lists among the targets in robotics for 2020 a number of aspects central to social communication such as “To extend basic interaction capabilities to exploit gestural, emotional, and intentional cues” and “To develop interfaces that can assess the emotional and cognitive state of the user and respond appropriately.''

Underpinning Research

The speech group at TMH (speech music and hearing) has a long record of world leading research on human-robot conversational face-to-face interaction[1],[2],[3],[4],[5]. Traditionally, conversational systems have been designed to handle the exchange of speech in task-oriented dialog, such as ticket booking or weather information. In such voice-only applications, the physical space where the interaction takes place is neglected, and the visual channel is not used at all. Think Alexa or Siri – it doesn’t matter where exactly the user is standing, what direction the user is facing, or whether the user is smiling or grimacing; the system is audio only. Moreover, the system is assumed to interact with a single user and does not recognize the difference between one user speaking or several. With the Furhat system, in contrast, several users may interact with the robot in one interaction. The visual channel (such as facial expressions) and the physical situation are taken into account, and many different types of interactions can be modelled.

Details of the Impact

Furhat Robotics is a KTH spin-off company that develops conversational robots and social robotics applications. Furhat’s core product is a social robotics platform, that enables creation of engaging spoken social human robot applications. These applications can be in any conceivable domain, but most use cases target public settings (as opposed to domestic applications). When the first version of the Furhat platform was released in 2014, many of the initial customers were from academia, interested in using the robot as a research tool in human-robot interaction, psychology and other areas. Since then, there has been a shift in the clientele towards commercial companies and organizations interested in deploying social robotics technologies in their operations. Today, Furhat has customers around the world, including: ICA-gruppen, Unicef, Ericsson, Arbetsförmedlingen, TNG Rekrytering, Uppsala Universitet, Örebro Universitet, KTH, Deutsche Bahn, BMW, MERCK, KPMG, University of Glasgow, University of Bielefeld, Disney Research, Northeastern University, University of Texas El Paso, Honda Robotics Institute, Bandai-Namco Studios and more.

In 2017, Balderton Capital & Local Globe invested 20MSEK in the company and in 2019 Furhat received a 10MSEK grant through the European Union H2020 SME instrument. These funds allowed Furhat to scale up it’s robot production (currently ongoing), mature its software platform and focus on developing several strong partnerships, aiming to establish the utility of social robots in real-world applications in wildly different segments.

Selected global media coverage on Furhat Robotics in the social robotics market:

Digital Journal: http://www.digitaljournal.com/pr/4591240

EU-Startups: https://www.eu-startups.com/2020/02/10-promising-european-robotics-startups-to-watch-in-2020/

ExpressComputer: https://www.expresscomputer.in/startup/5-promising-european-startups-to-look-out-for-in-2020/48660/

Below are some of the most prominent projects outlined.

Deutsche Bahn – FRAnny: is a robot concierge, built by Deutsche Bahn, deployed in the Frankfurt Airport. It is able to answer a wide range of questions ranging from identifying the correct gate, directing the way to places, and how to access Wi-Fi. In April 2018, Deutsche Bahn ran a pilot for a month under which the robot had 4400 passenger interactions (75% of which were rated positively by users). The trial was deemed a success by DB management, and a more advanced version of the system was developed; this system is being piloted at Berlin central station, and trials has been conducted also at Fraport and Tokyo central station.

Selected global media coverage on Deutsche Bahn robot concierge:

EU start-ups: https://www.eu-startups.com/2020/02/10-promising-european-robotics-startups-to-watch-in-2020/?fbclid=IwAR3JZR2DIG18bP7bpehDHeHfK-WBnVPEJvC7trtp0lxVTdyz3GKPV0cFsBw

IEEE Spectrum: https://ieeexplore.ieee.org/document/8784113

Frankfurter Rundschau: https://www.fr.de/frankfurt/kuenstlichen-intelligenz-deutschen-bahn-12950674.html

Tengai – Unbiased Recruitment Robot: TNG Rekrytering, a Swedish recruitment agency specializing in unbiased recruitment, is partnering with Furhat Robotics on the development of the world's first unbiased recruiter robot. The vision behind the robot is to better analyze, understand and perform competency-based interviews and assessments eliminating unconscious bias[6]. The first version of the robot recruiter was launched by TNG in May 2019.

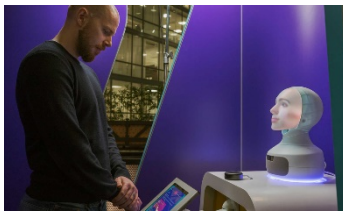
Selected global media coverage on TENGAI Unbiased recruiter:

The Times: https://www.thetimes.co.uk/edition/world/robot-is-just-the-job-as-an-unbiased-recruiter-hnrsz9qzr

Recruiter, UK: https://www.recruiter.co.uk/news/2018/11/furhat-robot-aims-turns-turn-recruitment-bias-its-head

Dagens Nyheter: https://www.dn.se/ekonomi/snackade-med-en-robot-fick-nytt-jobb/

Sveriges radio: https://sverigesradio.se/sida/artikel.aspx?programid=103&artikel=7286017



Merck - Medical Screening: Together with MERCK Pharmaceuticals, Furhat has developed Petra, a medical screening robot. Petra will interview the user in order to discover signs of three of common, yet under-diagnosed diseases: diabetes, alcoholism and hypothyroidism. The MERCK robot is designed to be placed in public areas e.g. shopping malls or train stations and was showcased at Epicenter in Stockholm in 2019.

Stockholms Stad – Robot Teaching Assistant: Furhat Robotics and Stockholms Stad collaborate on the use of social robots in schools. The aim of the project is to reduce the workload on teachers and find new ways for students to collaborate with each other. Furhat will be used as an interactive teaching assistant which can be customized by students with content such as presentations, lectures, Q&A's and quiz games. First pilots ran in two Stockholm schools in 2019.

Bandai Namco – Greeter for theme parks: Japanese game developer Bandi Namco (PAC-MAN, Tekken…) has done a pilot project with Furhat on building a greeter robot that can be deployed in theme parks or arcade halls. The robot was designed as a clone one of the company's own characters, Mirai Komachi.

Selected global media coverage on Bandai Namco Mirai Komachi anime greeter robot:

Crunchyroll: https://www.crunchyroll.com/en-gb/anime-news/2019/08/21-1/swedish-robotics-company-teams-up-with-bandai-to-build-anime-girl

Techcrunch Japan: https://jp.techcrunch.com/2019/08/20/bandai-namco-research-furhat/

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[1] Al Moubayed, S., Skantze, G., & Beskow, J. (2013). The Furhat Back-Projected Humanoid Head - Lip reading, Gaze and Multiparty Interaction. International Journal of Humanoid Robotics. 10(1).

[2] Skantze, G., Johansson, M., & Beskow, J. (2015). A Collaborative Human-robot Game as a Test-bed for Modelling Multi-party, Situated Interaction. In Proceedings of IVA. Delft, Netherlands.

[3] Al Moubayed, S., Edlund, J., & Beskow, J. (2012). Taming Mona Lisa: communicating gaze faithfully in 2D and 3D facial projections. ACM Transactions on Interactive Intelligent Systems, 1(2), 25.

[4] Skantze, G., & Al Moubayed, S. (2012). IrisTK: a statechart-based toolkit for multi-party face-to-face interaction. In Proceedings of ICMI. Santa Monica, CA.

[5] G. Skantze och M. Johansson, "Modelling situated human-robot interaction using IrisTK," i Proceedings of the SIGDIAL 2015 Conference, 2015, s. 165-167.

RPL Impact cases 7-9:

The paper Sharif Razavian, A., Azizpour, H., Sullivan, J., & Carlsson, S. "CNN features off-the-shelf: an astounding baseline for recognition". In *Proceedings of the IEEE conference on computer vision and pattern recognition workshops* (pp. 806-813), 2014, has been cited 3000+ times and highly influential for making Deep Learning practically useful in industry.

The paper Kazemi, V., & Sullivan, J. "One millisecond face alignment with an ensemble of regression trees". In *Proceedings of the IEEE conference on computer vision and pattern recognition* (pp. 1867-1874), 2014, describes the algorithm that is used by Snapchat for

face tracking. Vahid Kazemi, former doctoral student at PRL, leads this development at Snapchat.

Volumental AB spun out of the research on 3D modelling and is now a global company with customers in 38 countries. Their foot scanners have acquired a database with 3 million 3D foot scans. Customers include for example New Balance and Bauer. An article in Forbes gives one customer's story about the new technology https://www.forbes.com/sites/micahsolomon/2018/08/31/the-moneyball-of-feet-the-technology-enhanced-retail-customer-experience-at-fleet-feet/#5e2ae6e25415

DCS impact case 10

One of the main scientific success stories in DCS has been the pioneering work in distributed event-based control of multi-agent systems; from conceptualization and introduction of the first results in the field to major applications in process control and vehicular systems. DCS researchers have published the first and most cited papers in the area of distributed event-based control [1], [2]. In these papers, event-driven strategies were motivated by the use of embedded microprocessors with limited resources for communication and computation. It was shown that such strategies can be used to solve the classical agreement problem where a number of agents aim to reach consensus. These original papers considered some specific triggering rules and low-order dynamics. Later, these results have been extended by researchers world-wide to a large number of different cases with discrete- and continuous-time dynamics of both nonlinear and high dimension, and with a variety of triggering conditions. The survey paper [3], co-authored by a DCS researcher, is highly cited and gives an overview of the many directions the development of the area have taken.

The impact of the work on distributed event-based control can be illustrated by how it has influenced the scientific community, not only through citations but also in the organization of new conferences and other initiatives. Let us in particular mention

1) A large number of workshops and invited sessions at the top conferences in control, such as the IEEE Conference Decision and Control, the American Control Conference, and the IFAC World Congress, have been dedicated to event-based control of multi-agent systems;

2) The newly established IEEE International Conference on Event-Based Control, Communication and Signal Processing focuses to a large extent on this topic, and DCS researchers have given keynote presentations at the conference;

3) A number of survey papers appearing in leading journals and conferences has been published.

Distributed event-based control has already made an impact in a number of application areas, such as communication networks, real-time scheduling, autonomous vehicles, mobile robotics, and process control. Trade-offs between required communication rate and estimation quality have been studied for event-based sensor data scheduling. When it comes to autonomous vehicles, DCS researchers have applied and expanded the techniques to the fields of coordinated and distributed control of autonomous vehicles, such as ground, aerial and underwater vehicles, funded through a number of national and

EU funded projects. In collaboration with Swedish process industry, event-based control has been extended to feedforward control and applied to a pulp and paper plant.

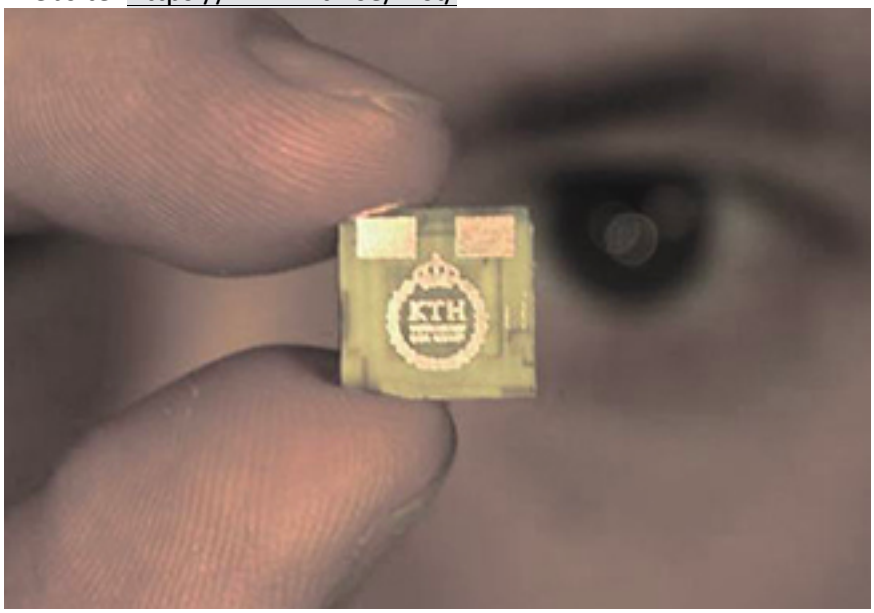
[1] D. V. Dimarogonas, E. Frazzoli and K. H. Johansson, Distributed event-triggered control for multi-agent systems, IEEE Transactions on Automatic Control, Vol. 57, No. 5, pp. 1291-1297, May 2012.

[2] G. S. Seyboth, D. V. Dimarogonas and K. H. Johansson, Event-based broadcasting for multi-agent average consensus, Automatica, Vol. 49, No. 1, pp. 245-252, January 2013.

[3] W. Heemels, K.H. Johansson, P. Tabuada, An introduction to event-triggered and self-triggered control, 51st IEEE Conference on Decision and Control, 2012.

2.2. The Division of Micro and Nanosystems (MST)

Website: https://www.kth.se/mst/



1. Overall analysis and conclusion; strengths and development areas

a. Limited SWOT-analysis (GS)

Strenghts in research

- Our multidisciplinarity makes us versatile and adaptable to creatively tackle new research areas and challenges.
- Internal (KTH) and external (national and international) cross-disciplinary collaboration; large national and international network in academia and industry.
- Success in publication strategy (> 20 publ. in journals with IF >10)
- Strong and increasing external funding record. (>250% during the assessment period)

Strengths in organization

- Flat organization, collegiality, transparency and positive team spirit.
- Being part of the IS department with an aligned research excellence culture and focus.
- Access to strong and unique (national) and multidisciplinary research infrastructure.
- International visibility and attractiveness in the MEMS/NEMS scientific community and industry.

Weakness in research:

- 5/7 faculty members did their PhD at the division (inbreeding), although new faculty recruitment rules mitigates this for the future.
- A lot of our research impact occurs in areas outside our core competence in MEMS/NEMS (e.g. in medical, bio).
- Very diversified research topics. A lot of focus on applied research topics.
- Our core research field (MEMS) is maturing and decreasing in impact (JcF of core MEMS journals is decreasing significantly).

Important future development areas:

We will continue our successful research in the application areas of Medical; Bio/NanoFluidics; Organ-on-Chip; RF, microwave and THz technology; Optics/photonics, and; Micro- and nanosystem integration.

We will engage in new research areas, both basic and applied: **Life Science/Medical and sensing technology**, specifically: biohybrid systems, translational drug delivery,

biomolecule sequencing, and environmental sensors for sustainable society; **ICT and transport,** specifically THz microsystems, and; **Advanced materials and nanotechnology,** specifically Quantum technologies and Programmable matter.

b. Summary statement on contributions of department on impact, infrastructure and sustainable development

Contributions to gender balance:
Our female PhD and postdoc students are highly active promoting internal networking. Their initiative is now the EECS female student network.

2. Research profile

MST is the leading Swedish academic MEMS and NEMS group. Internationally well-recognized multidisciplinary team with scientific excellence and good leadership abilities. It is predominantly composed of young research leaders exhibiting complementary competences, diverse backgrounds and strong internal collaborations. The researchers at the MST division have a high publication impact and are highly visible in their communities. The division has had a stable and high research funding level, with the majority of funds coming from the European Commission and national Swedish funding sources. In addition, our researchers have established interdisciplinary collaboration networks involving key academic and industry players in the field, both on national and European level.

a. General information of the division

Persons: Currently 50 (?) persons: 7 faculty (4 Full professors, 3 Assoc. Prof.); 3 permanent researchers; 2 technicians; 5 (?) Postdocs; 35 (?) PhD students.
Activities: 90% research; 10% teaching
Growth: Personnel approx. 7% annually for the past 20 years.

b. Central research questions and themes, knowledge gaps addressed, main research activities and composition of research team(s)

Micro and Nanosystems (MEMS/NEMS) and their application in Medical; Bio/Nano Fluidics; Organ-on-Chip; RF, microwave and THz technology; Optics/photonics; and Micro- and Nanosystem Integration. See www.kth.se/mst for more info.

c. Contributions to the advancement of the state of the art within the research fields of the department

Major contributions/pioneering work 2012-19 includes:

- We introduced the off-stoichiometric thiol-ene (OSTE) polymer system
- Pioneering graphene-based NEMS sensors
- New drug delivery modalities
- Pioneering the THz frequency spectrum, by novel device and system concepts enabled by micromachining
- Novel in vitro models of tissue
- Novel femtosecond laser 3D printing and micro and nanomachining approaches
- Novel nanogap and nanopore devices for biomolecule sensing and sequencing.

d. Quality and quantity of contributions to the body of scientific knowledge

Since 2017, and in line with KTH incentives, we assumed a focussed publication strategy to submit manuscripts to the most suitable journals with a high impact factor (IF). In particular, writing for multidisciplinary science journals forces us to describe our work in a broader perspective. We consider acceptance in such journals a measure for the potential impact of our work. We believe that this strategy leads to dissemination of our work beyond our direct peers in science, which we think can result in a potentially larger impact. We also believe that this strategy increases the attractiveness of the students in their career; the attractiveness of the PIs for potential collaborators; the chances in attracting excellent Ph.D. and postdoc candidates; the chances of a positive outcome in research funding applications; and the overall ranking of KTH. **The result is that the 2015-2017 average Cf is 1.13, and the 2016-2018 average JcF is 1.78.**

List of the distinctly increasing number of publications in journals with IF > 10:

2020 (Jan-Apr): 2x Nat Biomed Eng (IF 17.1), Nat Commun (IF 11.8)

2019: Science (IF 41), Nat Med (IF 30.6), Adv Mater (IF 25.8), 2x Sci Transl Med (IF 17.2), Chem Mater (IF 10.2), Nat Commun (IF 11.8), Nano Lett (IF 12.2), Nat Electron

2018: 2x Adv Mater (IF 25.8), ACS Nano (IF 13.9), Adv Fun Mater (IF 15.6), Nat Commun (IF 11.8), Sci Adv (IF 12.8)

2017: Nat Biomed Eng (IF 17.1)

2016: Adv Mater (IF 25.8), ACS Nano (IF 13.9)

2013: Nano Lett (IF 12.2)

2012: Adv Fun Mater (IF 15.6)

e. Engagement in national and international research collaboration within academia and its outcomes

MST is involved in many large European research collaborations and several national framework grants, involving academia. We collaborate with >50 academic/research institutes and research-intensive companies, for examples, see https://www.kth.se/mst/research/external-partners-1.58117

f. Follow up from previous evaluations (GS)

6.1 Microelectromechanical Systems (MEMS)

- *Suggests closer ties to industry. Infrastructures such as maintaining an industrial advisory board should be encouraged. Specifically, regular board meetings and annual workshops on focused technical topics would enhance the general impact and connections of the group's activities.*
- *Areas of concern:*

- *Research behavior strongly driven by need for funding*
- *Too much emphasis on short-term projects (JO: not correct; we have many 5-years frame-work grants)*
- *Participation in very many consortia-type EU projects*
- *Little scope for unfunded pilot research (JO: not correct; the post-docs Piotr and Ilya explored topics which were not funded)*
- *Expansion of group has led to increase in breadth not depth*
- *Some intention to expand into nanotechnology, but ancillary to MEMS (JO: is it compulsory to go to nano?)*
- *Lack of fundamental theory development (not correct: Oleksandr is doing fundamental work on filter design theory, WW is investigating imbibing phenomena in nature)*
- *Lack of fundamental research driven by need to seek project funding*
- *Lack of industrial board and industrial meetings*
- *Need more risk taking in technology development (JO: for my group, I think we take too many risks)*
- *Limited long-term strategic vision (JO: cannot agree from my side)*
- *Need a proper focus on NEMS and nano (JO: why is nano compulsory?)*

This is how we addressed the suggestions from RAE 2012:

1. *"More research which is focused on exploring the 'bottom end' at the nanoscale would enhance the unit's activities. Particularly, the group should try to identify new phenomena."*

We have initiated several projects with focus on components/devices governed by nanoscale features and phenomena, including graphene-based NEMS sensors [ref], nanogap electrodes for electron tunneling devices [ref] and nanopore devices, as exemplified in https://www.kth.se/mst/research/nems-and-nanosystems.

2. "*This increasingly competitive area necessitates strategic investment in longer-term research goals, which should include physics and new materials, as well as technology."*

We have an increased focus on nanotechnology, micro and nano 3D printing, and material research, reflected, e.g., in publications in *Advanced Materials, ACS Nano, etc*.

- graphene
- programmable matter
- biomaterials and biohybrid materials (spider silk, cell encapsulation, DNA-templated structures)
- electron tunneling devices and nanopore devices for biomolecule sensing
- organic electronic materials
- translational research
- micromachining for exploiting THz frequencies, which we clearly are leading in Europe
- 3D printing of glass micro and nanostructures
- 3D printing for organ on chip applications.

3. "*The panel suggests closer ties to industry. Towards that end, infrastructures such as maintaining an industrial advisory board, to provide future directions, in research and professional development would be encouraged."*

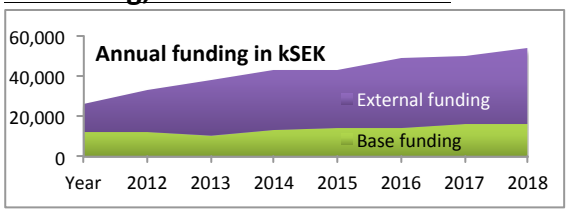
We consider this a valuable suggestion and have extended our collaborations with industry in various projects, and we have increasing implemented industrial project advisory boards

in most of our projects such as in “SSF Next Generation Laser 3D Micromachining”, Horizon2020 ZeroAMP, etc.

We have many projects with an industrial advisory board; we cannot have an overall industrial advisory board for such broad activities.
All our EU projects are with industry and all faculty have projects with direct industry funding.

3. Viability

a. Funding; internal and external



- Annual funding increased from 27.5 Mkr in 2012 to 57.5 Mkr in 2019, almost entirely through external funding.
- Several prestigious external grants: 3 ERC Grants; 6 ERC PoC Grants; 3 KAW Grants; ;1 Research Environment Grant from the National Research Council (QuantumSense); Coordination of 7 EU Projects (NOROSENSOR, ICU, ROUTINE, INTOPSENS, POSITIVE, M3TERA, Car2TERA); Total > 25 EU Projects in the past 10 years, incl. 3 Marie-Curie ITN and 1 FET Open; 3 Framework Projects from the Swedish Foundation for Strategic Research.
- Prestigious KTH internal funding: 1 KTH Tenure Track, 1 Digital Futures project.

b. Academic culture

The academic culture in our division is highly collaborative within our division and across research disciplines, regionally, nationally and internationally, as well as in between academic and industrial research environments.

Regionally we are increasingly involved in lifescience and medicine-focused projects with academia, clinics and industry, e.g. via MedTechLabs (www.medtechlabs.se) driven by Region Stockholm, Karolinska Institute and KTH.

In the international research community, MST faculty is proactive via conference organization (IEEE MEMS: WW chairman 2015; GS, WW in ISC, NR, FN in TPC; TRANSDUCERS: GS Chairman 2025; GS, WW, FN in ETPC; MICROTAS: WW in ETPC; Waferbond: FN Chairman 2013) and via editorial board membership (GS in IEEE J MEMS, WW in J Micromech Microeng, GS in Microsys Nanoeng, JO in IEEE T THz Sci Techn, AH in Frontiers in Toxicology) and as guest editors (AH for Adv Mater, AH for Macro, WW for Front Mech Eng).
The evolution of the MEMS research field from research to industrial development makes it natural for academic MEMS research to develop and specialize on specific applications, a trend we both drive and follow. This poses a challenge in maintaining the traditional MEMS community but opens possibilities in building/integrating in application-focused communities.

c. Current employment situation

- Our group grew >60% since 2012.
- PhD and postdoc recruitment pends external funding.
- Our current faculty situation is adequately positioned to addresses strategic future development areas as listed above.
- Our group is truly international, with 88% having international background.
- We evolve towards a more equal distribution of different career stages, specifically by an increase in postdocs and permanently employed researchers.
- Gender balance improved infinitely on faculty level (0% 2012 → 14% 2020), remained equally bad at PhD level (around 14%), and strongly improved on postdoc level (0% 2012 → 38% 2020).

d. Recruitment strategies

We announce our open positions via targeted international communication channels (e.g. LinkedIn), resulting in >90% of applicants from outside Sweden.
Our multidisciplinarity attracts candidates from diverse educational backgrounds.
Our positions are attractive, often >50 candidates per position, allowing us to select suitable candidates.

e. Infrastructure and facilities

See IS level description in section 2.1.

4. Strategies and organization

a. Goals for development 5–10 years ahead (JO)

Our plan is to reinforce and develop the position of MST as one of the leading micro- and nanosystem research groups worldwide. To achieve this, we work in multidisciplinary research collaborations with selected partners, with whom we research innovative micro- and nanosystem solutions for improving energy, healthcare and ICT applications by demonstrating smaller, higher performing or lower cost components and systems that address and respond to the grand challenges of industry and society in these areas. We use (1) novelty and (2) relevance of our research as the combined guiding principles. Our current partner network includes world leading experts. Whilst continuing collaborations with our existing partner network in existing and novel constellations, we plan to increase collaboration with healthcare professionals and industries, and take a proactive role in major centre formations.
As a multidisciplinary division we are uniquely positioned to leverage on research collaborations with other academic groups and to cross-fertilize into new areas. The MST division therefore encourages visits from other scholars as well as faculty-initiated research relations with other universities. Currently our faculty has relations for example with Harvard University and with MIT.
We will continue our successful research in the six major application areas mentioned above but also expand further in the following new research areas: **lifescience/medical technology**, specifically: biosensors, biohybrid systems and translational drug delivery; **sensors**, in particular environmental sensors for sustainable society; **ICT and transport**, specifically THz microsystems for telecommunication and radar applications, and; **advanced materials and nanotechnology**, specifically quantum technologies and programmable matter.

b. Congruence with university-level goals and the school(s) development plan(s)
see IS level description in section 2.1.

c. Leadership structure and collegial structure

- Transparent and inclusive leadership style.
- Weekly breakfast meetings with the entire MST division, discussing all aspects of academic life.
- Monthly faculty meetings.
- Regular group and project meetings across the groups of the faculty members.

d. Strategies for high quality
Target high-quality, innovative and relevant research.
Bibliometry and community involvement are our main measures for research quality.

5. Interaction between research and teaching (JO)

MST teaches 4 courses at BSc level, 3 at MSc level and 13 at PhD level. For details, see https://www.kth.se/mst/education.

All our teaching is strongly connected to our research, which results in high-quality teaching, as reflected in the students' feedback. Herein, students are initiated in our core research areas. Furthermore, master thesis and PhD students are part of our teaching and scientific work. We also supervise several industrial master thesis students which emphasizes the industrial/societal relevance of our research and teaching competence.

6. Impact and engagement in society
See IS description level description in section 2.1.

2.3. The Division of Robotics Perception and Learning (RPL)

Website: https://www.kth.se/rpl

1. Overall analysis and conclusion; strengths and development areas

a. Limited SWOT-analysis

Strengths in research

- Multidisciplinary faculty covering the broad research topics of robotics, perception and machine learning.
- A well balanced combination of junior and senior faculty that provides excellent support for the doctoral students in both broad and focused research topics.
- Strong external funding that, compared to 2012, is more homogeneously distributed between the faculty at the division.

Strengths in organization

- Collegial and transparent culture faculty explores his/her own research ideas.
- Between 2012 and 2018 RPL recruited eight new faculty members. RPL changed from six to 13 faculty (one professor retired) in less than six years and successfully integrated everyone into RPL to form an even stronger division community.
- Faculty consists of five female and eight male researchers. This is a big strength when it comes to recruitment. Our candidates choose RPL when given a choice because we do not just talk about gender balance, we have it.
- Eleven industrial doctoral students and more on the way, provide direct connection and collaboration with our industrial partners.

Weaknesses in research

- The relatively high teaching and administrative load compared to other divisions means that the researchers do not have so much time to engage in research and most of the research is done via doctoral and postdoctoral students.
- Giving each faculty the freedom to pursue research in his/her own direction means that we sacrifice the ability to muster a large coordinated research effort.

Weaknesses in organisation

- The downside of the collegial spirit is that there is no single strong leader that points in a single direction. This would allow us to generate more impact in one or a few areas. However, the price would be less robustness and less diversity.
- Too few postdocs (six) for the size of the division.
- RPL is currently split across two addresses (Teknikringen 14 and Teknikringen 33) which puts extra strain on communication and collaboration.

2. Research profile

RPL is the result of a merger between the division CVAP and most of the KTH center CAS.

a. General information of the division

Persons: 13 faculty (4 professors, 6 associate professors and 3 assistant professors), 1 researcher, 6 postdocs, 53 doctoral students and 5 research engineers.

Activities: 83% research and 17% teaching

Funding: For 2018 the earnings for RPL was 13.3MSEK (17%) education, 21.7MSEK (27%) faculty funding, 39.1MSEK (49%) external funding and 5.4MSEK (7%) in other earnings.

Growth: Between 2012 and 2018 RPL recruited 8 new faculty members and grew from 6 to 13 (one professor retired). The number of doctoral students has also increased steadily.

b. Central research questions and themes, knowledge gaps addressed, main research activities and composition of research team(s)

The largest subfield in robotics is manipulation and grasping, with a focus on highly deformable objects such as fabrics, addressing some of the open needs in domestic and industrial applications. We also explore how to enable learning of robotic behaviors for problems where both action and sensing is uncertain and highly dynamic. Furthermore, we explore how to transfer solutions generated in simulated environments to the real world given that the simulation is typically a crude approximation of the real world. A central question in robotics is that of interaction with humans. We study the challenges connected to enabling robots that can manage efficient and engaging long-term interaction with people in real-world situations. This means that the robots must be able to *capture*, *learn* from and *respond* appropriately to the subtle dynamics. With the establishment of the new Swedish Maritime Robotics Centre (SMaRC) in 2017, RPL has built up a large activity around autonomous underwater vehicles (AUV). Here we target several of the core SD questions, but again at a longer horizon than 2030. We provide the basic functions such as underwater navigation and planning that will then enable the target applications. Three examples of such are: SEA Farm Algae cultivation, surveying for offshore industrial applications such as wind farms and support oceanographic teams that are using AUVs to collect data to model the melting effects of ocean currents under the Antarctic ice to better predict ocean level rise.

We are working on correct-by-design planning, motion planning, and control for autonomous systems to enable their safer, more effective, efficient, and socially acceptable movement. Related to this, we use behavior trees as a way to model the switching between tasks in an autonomous agent, with tools for formal analysis of robustness and safety.

In the intersection between computer vision and machine learning, we work on recognition and interpretation of human and animal nonverbal behavior. Tight collaborations with researchers in speech communication and interaction design complement this.

Deep learning has become a standard tool in most fields of research. It is powerful but not yet well understood theoretically. We contribute work on several key challenges. We work on explainability in deep learning decision making processes and propose to represent the human-interpretable explanations as part of the process. This will ensure that in that representation space we have an interpretable explanation that caused the decision. We also develop methods to accompany deep network predictions with uncertainty estimates in an efficient manner and to deal with overconfident network predictions. In addition, we work on deep transform learning and domain adaptation. In another strand of work on machine learning we study geometric-topological machine learning methods. This allows for reliable, hierarchical and efficient mechanisms for reasoning, for example, about motion. In particular we study the gap between low-level geometric reasoning and hierarchical abstraction.

Multidisciplinarity and composition of teams

It is difficult to quantify multidisciplinarity. The 13 faculty at RPL have PhDs in the following areas: robotics, computer vision, machine learning, human robot interaction, formal methods, control and mathematics. On a per project basis we look to extend this further from other divisions, departments, schools, our outside KTH when needed.

We believe in the power of the individual researcher picking their own direction where he/she has a burning interest to explore in contrast to forming research teams in a top down manner based on the vision of a few. Teams are formed bottom up, driven by interest and the desire to work together. Looking at the current formation of teams, both between faculties and faculty and students there are some indications that gender influences team composition, but given the small numbers drawing any conclusions from this is speculation.

c. Contributions to the advancement of the state of the art within the research fields of the department

Below is a list of contributions to the advancement of the state of the art in the research topics at RPL.

- A. Sharif Razavian et al., “CNN features off-the-shelf: an astounding baseline for recognition”. In *CVPR workshops* (pp. 806-813), 2014, has been cited 3000+ times and highly influential in the field of computer vision.
- G. Castellano et al., “Detecting User Engagement with a Robot Companion Using Task and Social Interaction-based Features”, ICMI 2009, won the ten-tear technical impact Award at ACM ICMI 2019.
- We were the first to move the AI tool Behavior Trees into the area of robotics and have the highest cited papers on behavior trees in robotics.
- A. Billard and D. Kragic, “Trends and challenges in robot manipulation”, Science 364 (6446), gives a survey paper on grasping and manipulation in Science.
- In our work on correct-by-design planning, motion planning, and control for autonomous systems, we have developed maximally satisfying temporal logic-based planning algorithms and applied these in autonomous driving scenarios with road rules.

- Together with Alzheimer specialists at Karolinska Institute / Karolinska Hospital we have contributed to the detection of early signs of dementia from verbal (speech) and non-verbal (motion, face, gaze) behavior.
- Together with large-animal veterinarians at Swedish University of Agricultural Sciences / Ultuna Animal Hospital in Uppsala we have developed novel mechanisms for detection of signs of pain in horses from video of their motion and behavior.
- We give autonomous underwater vehicles enhanced navigation and perception abilities that allow them to work in application currently requiring expensive ships and crews. This includes methods to automatically interpret sonar data in ways impossible for humans to achieve.
- We predict traffic surrounding autonomous trucks and busses. These predictions include the interactions between vehicles and give multiple possible futures along with measures of uncertainty.

d. Quality and quantity of contributions to the body of scientific knowledge

The school of EECS has a publication policy which we largely follow. ArXiv dominates in our area as a way to ensure that publications are available open access. ArXiv in combination with KTH's Diva leaves very few cases where other open access alternatives are needed. We aim for the highest impact venues, but always keep the doctoral student in mind. A doctoral student has to be given opportunities to practice writing. During the first years this could mean targeting a lower ranking venue. RPL's bibliometric performance is top three at the school of EECS.

The following publications are highlighted for reasons defined below.

- A. Sharif Razavian et al., "CNN features off-the-shelf: an astounding baseline for recognition". In *CVPR workshops* (pp. 806-813), 2014, was one of the first papers to show how powerful transfer learning is. Highly influential in computer vision.
- V. Kazemi, J. Sullivan, "One Millisecond Face Alignment with an Ensemble of Regression Trees", CVPR, 2014, led to what is now powering Snapchat's face tracker.
- A. Marzinotto et al., "Towards a unified behavior trees framework for robot control", ICRA, 2014, introduces behavior trees into robotics. They are a well-known tool in computer games. We believe that they will play an instrumental role as systems become increasingly more complex.
- A. Billard, D. Kragic, "Trends and challenges in robot manipulation", Science 364 (6446), 2019 in one of very few pure robotics papers in Science.
- R. Vinuesa et al., "The role of artificial intelligence in achieving the Sustainable Development Goals". ***Nature Communications*** 11, 233 (2020) is an important contribution by analyzing the effects of AI on the SDGs.

e. Engagement in national and international research collaboration within academia and its outcomes

- RPL is heavily involved in the national project Wallenberg AI, Autonomous Systems and Software (WASP). WASP started in 2016 and runs until 2029 with a total budget of 5.5BSEK. RPL faculty directs the WASP AI/MLX initiative. The most important instrument of WASP is the graduate school, which currently has more than 200 doctoral students enrolled. RPL faculty represent KTH in the management boards of

both tracks: i) Autonomous Systems and Software and ii) AI. WASP provides a unique network in Sweden.

- Swedish Marine robotics Centre, SMaRC, is a SSF funded project running 8 years. Partners include SAAB Dynamics, SAAB Kokums, MMT, Gothenburg University, Stockholms University, Deep Vision, as well as four divisions at KTH. There have been collaborations in SMaRC with the National Oceanographic Center in the UK, University of Porto, as well as several other groups in Europe.
- RPL has an extensive collaboration with the Perceiving Systems department at the Max Planck Institute for Intelligent Systems in Tübingen, Germany. Professor Kragic is on their Advisory Board. Professor Kjellström is an Affiliated Professor there.
- RPL has an ongoing collaboration with MIT on formal methods-based autonomous driving and with Oxford University on deployment of formal methods in long-term autonomy, with Stanford University on formal methods fused with reinforcement learning. The collaborations are strengthened by bidirectional weeks to months long research visits of PhD students and postdocs.
- RPL is involved in one of the few or first fluid mechanics and deep learning collaborations in the world. It has already resulted in a couple of papers.
- The research on social robotics has two main groups of stakeholders or lead users. First, companies developing intelligent robots such as ABB, Furhat Robotics (a spin-off from KTH) or Atlas Copco. The second group of Stakeholders is the public sector. We recently conducted a study at a school to investigate the use of robot-mediated activities to bring together children who are newly arrived to Sweden and settled groups.
- RPL faculty make up the larger part of the board of the IEEE-RAS Swedish Chapter. As such we organize events like conferences on teaching RAS topics, PhD poster sessions and industry-PhD meetings.
- RPL organised the largest robotics conference in Stockholm 2016, holding positions such as general chair, local chair, finance chair and exhibition chair in the organisation.

f. Follow up from previous evaluations

The recommendations from RAE 2012 are included below in italics with comments.

Encourage a climate of intellectual integration of the different groups perhaps through a key hire who could bridge the two primary areas of neuroscience and robotics.

There is now a person at the division CST with a robotics background that can act as this bridge but the reorganisation of KTH has now placed RPL and CST further apart than before in the organisation. Still in the same school, but at different departments where the new departments are like the previous schools in size.

The research activities seem to depend to a great extent on obtaining external funding. This bears the risk of discouraging long term and risky research initiatives since the faculty is under intense pressure to produce results to justify additional grants. The time devoted to generating grants also seems to be quite high.

The WASP project is now a major funding source for RPL. The funding is still competitive within WASP but not as competitive as most other sources once you are inside the project. RPL has a unique position within WASP, at least at KTH given that we fit right in the middle or both Autonomous Systems and AI, i.e. two of the biggest areas in WASP. The threat with WASP is that we might become too dependent on it.

The process to hire new faculty seems to require time well above the international average, which clearly puts the institute at a disadvantage relative to competing institutions around the world.

We could not agree more. KTH is incredibly slow in the recruitment process. As a division we can help this to some degree by working proactively with the candidates, but this does not allow us to come anywhere near competitive performance in the hiring.

The most successful instrument that was implemented as a result of RAE 2012 were the so-called Small Visionary Projects (SVP) at the old CSC school. These were seed projects that encourage collaboration across division borders. They brought RPL much closer to TMH, which was part of the same unit of assessment and is now part of the same department.

3. Viability

a. Funding; internal and external

The funding for RPL is split roughly equal between external and internal funding. Internal, here refers to funding for teaching (17%), faculty funding (27%) and other (7%). External funding (49%) comes from a range of different instruments, both national and international.

During the last ten years RPL has had

- 17 EU projects (in alphabetic order) CENTAURO, Co4Robots, CogX, ECHORD, ENTimeMent, eSMCs, FINE, GRASP, PACO PLUS, REConfig, RobDream, ROBOHOW, SaraFun, socSMCs, STRANDS, TOMSY, TRADR,
- 16 projects from the Swedish Research council (VR)
- 6 large national projects from the Swedish Foundation from Strategic Research (SSF)
- 5 projects from Sweden's innovation agency (VINNOVA)
- 2 Future Research Leader grant (SSF)
- 1 ERC advanced grant ("BIRD") and 1 ERC consolidator grant (Flexbot)
- 1 Distinguished professor 10-year grant from the Swedish Research council

Since 2016, when the national project WASP started, RPL has gradually increased the amount of external funding from that source. Currently it funds about 3 FTE faculty and a large number of academic and industrial doctoral students at the division. The project runs until 2029. While this is today the single largest source of funding at RPL, and as such as risk, almost all faculty members have funding from other sources as well.

b. Academic culture

The most frequent meeting place where research questions are discussed are the seminars that all RPL students have to deliver to move to the next step on the salary ladder, i.e. at 30%, 50% and 80% of the requirement for the thesis. After the discussion with everyone, faculty meets and discusses the work and the supervision. The 50% seminars are mandatory for all members of RPL, and other seminars have to be announced to all.

All members of the faculty at RPL are part of the management board of RPL. We meet once a month to discuss and make decisions and form strategies.

RPL has workplace meetings for all employees once a month. These meetings are led by the head of division. Since a year back we end each meeting with a presentation by a faculty member to put research on the agenda.

Twice a year we organize seminars where all members of RPL can present what they are working on. This has been running for three years. The seminars are typically arranged after the big conference deadlines in the spring and the fall. The presentations are kept short to allow for a 2h overview of the current work at RPL.

The more technical details are typically discussed in meetings between supervisors and students and within projects. These are the types of meetings that do not need external forces to be sustained. The previous examples do.

c. Current faculty situation

RPL's main research topics have increased significantly in interest over the last 10 years. As a result of this and strategic work, RPL has grown. Right now, there are a total of four professors, five associate professors and four assistant professors out of which two, two and one are females respectively. Eight new faculty members have been recruited since 2012 and one has retired. It will be challenging to keep the balance across different career stages going forward given that many are still so young. In the next 15 years only two people are predicted to retire.

d. Recruitment strategies

For the recruitment strategy of faculty members, please see the overall IS description.

Postdocs

Compared to the number of doctoral students, RPL has relatively few postdocs. One contributing factor to this is that many of the faculty are relatively junior and in a stage in their career where supervision of doctoral students is critical. We are currently planning to open broad postdoc positions at a division level as an initiative to find the best postdocs without the added constraint that they also have to fit into a specific research project.

Recruiting the very best postdocs in the field is very challenging at the moment given that many companies today are trying to build up in-house competence in core areas of RPL. Higher salaries and more resources in industry have always been impossible to match in academia. New is that some companies are also leading actors in basic research.

Doctoral students

All doctoral studentships are announced publicly. A vast majority of the applicants are from abroad. This is great as it facilitates an influx of good people to KTH. However, we see the low number of applicants from our "own" students from KTH as an area where we can and should try to improve to better utilize the resources that we spend on education, especially at second cycle. RPL faculty members teach in more than 20 courses, most of which are connected to the research topics at RPL. This provides good visibility towards students at KTH. Currently we have more than 80 Master's degree projects running at RPL. RPL directs two of the largest masters programs at KTH, Machine learning (TMAIM) and Systems, Control and Robotics (TSCRM). We have defined a project course (DD2411) that allows individual students to spend a full year working in research projects which will prepare them in a unique (at KTH) way for the thesis project and future research studies. We routinely hire students at KTH as research engineers to work in research projects. We are initiating a Fellow program for BSc and MSc students to further strengthen this.

As part of a long term effort towards better gender balance, RPL has participated in the past two editions of "The Future needs GIANTS", an event for increasing the number of women in Computer Science and Engineering programs at KTH. We have also participated

in all “Tekla festivals” (an event initiated by the artist Robyn) organized at KTH, also with the aim to increase women’s interest in technical subjects.

4. Strategies and organization

a. Goals for development 5–10 years ahead

RPL is an attractive and highly visible workplace where excellence in research and teaching coexists and where gender balance is not just talked. An important element of such a strategy is to have broad announcements for positions. RPL remains the go to place at KTH for the core topics studied at PRL and is a major player in Europe. In a few selected narrower topics, we are world leading like we have been so far in, for example, manipulation and grasping.

b. Congruence with university-level goals for research as set out in “A leading KTH - Development Plan 2018-23” and with the school(s) development plan(s) respectively.

As a result of the recent reorganization we follow mainly the development plan for the department of Intelligent Systems.

c. Leadership structure and collegial structure

RPL is managed by a head and vice head of division, that lead the day to day operations. The head of division is formally responsible for all projects, but the project leaders are de facto responsible. Each faculty member has at least two doctoral students and is his/her own project leader with informal decision power to manage the projects.

A director of studies manages the division’s courses. All the faculty together form the management group of the division. The management group meets once a month to discuss important topics before decisions are made. The head and vice head meet with a student representative every second week to ensure that student opinions are captured.

5. Interaction between research and teaching

a. Interaction between research and teaching at all three levels (BSc, MSc, PhD) of education

RPL teaches in more than 20 courses, mainly at MSc level. At MSc level, most courses are connected to and inspired by our core research topics. Our two largest courses, Machine Learning and Artificial Intelligence were so large that they had to be split in two course rounds. Each course attracts 500-700 students in total each year. RPL faculty members direct two of the largest master programs at KTH; Systems, Control and Robotics (TSCRM) and Machine Learning (TMAIM). These two programs were both created motivated by our research and the desire to educate students in our topics to improve recruitment.

At BSc level our teaching to date is in general CS topics such as databases and programming. However, we are currently involved in the development of a new machine learning course which will be at BSc level.

At a doctoral level our courses are mostly internal in nature. Some of the courses at MSc level were developed as a doctoral level course and then adjusted to fit for MSc. Some of our courses run in parallel as both MSc and doctoral level courses with different examination requirements but some shared teaching activities such as lectures.

2.4. The Division of Information Science and Engineering (ISE)

Website: https://www.kth.se/ise

1. Overall analysis and conclusion; strengths and development areas

a. Limited SWOT-analysis

Research

Strengths: International visibility and recognition. Secured funding for basic research. Existing contributions to several application areas, strong foundation in basic science opens up for contributions to additional important applications.

Weaknesses: Activities rely heavily on funding for basic research, the competition to secure such funding is increasing. Strong dependence on external funding received in competition limits the willingness to take substantial risks in the pursuit of new topics.

Organization

Strengths: Flat organization with strong anchoring of important decisions. Strong sense of unity and sharing of common principles.

Weaknesses: Implementing a flat structure is a challenge as the division grows.

Development areas

Strategy for securing a larger portion of the available funding for basic research.

2. Research profile

a. General information of the division

We are 8 Full Professors and 4 Associate Professors. We also host one Adjunct Professor (employed by Ericsson) and one Adjunct Faculty Member (employed by ABB). As discussed in Sec. 4.c, the Division advocates a flat organizational structure below the level of division.

Our Faculty members are highly successful and recognized researchers in their respective fields. **Tangible proof of professional recognition includes**: *Editorships (EiC)*: EURASIP Signal Processing; *Editorial Boards*: IEEE Trans. on Information Theory, IEEE Trans. on Signal Processing, IEEE Trans.

on Circuits and Systems for Video Technology, IEEE Trans. on Information Forensics and Security, IEEE Open Journal of Signal Processing, IEEE Open Journal of the Communications Society, IEEE Signal Processing Letters, IEEE Trans. on Wireless Communications, IEEE Trans. on Communications, IEEE Communications Letters, IEEE Wireless Commun. Letters, Foundations and Trends in Signal Processing, EURASIP Journal on Advances in Signal Processing, EURASIP Signal Processing; *TPC chairing*: IEEE ISIT 2022 (TPC co-chair, upcoming), IEEE ISWCS 2018 (TPC co-chair), SPAWC 2015 (TPC co-chair), SPAWC 2013 (track chair), Asilomar 2016 (area chair), ICASSP 2020 (track chair), IEEE WIFS 2019 (special sessions), ISWCS 2020 (invited sessions), SPAWC 2015 (invited session), SPAWC 2013 (invited session); *Conference general chairing*: IEEE ITW 2019, IEEE SPAWC 2015; *Technical Committees and Boards*: IEEE Signal Processing Society Committee on Signal Processing for Communications and Networking, IEEE Signal Processing Society Technical Directions Board (TDB), IEEE Signal Processing Society Fellow Committee, IEEE Signal Processing Society Awards Board (Chair), EURASIP Fellow Committee, EURASIP Board of Directors, IEEE Fourier Award Board, IEEE Signal Processing Society Board of Governors; *Society Fellowships*: Two of the faculty members are IEEE Fellows, one is in addition a EURASIP Fellow; *Boards of Foundations and Councils*: Swedish Research Council; Swedish Foundation for Strategic Research; Villum Foundation, Denmark.

b. Central research questions and themes, knowledge gaps addressed, main research activities and composition of research team(s)

What are the fundamental limits in communication, processing, and learning?

We employ mathematical modeling and information-theoretic concepts to identify ultimate performance limits that govern communication, processing, and learning (e.g., capacity, complexity, uncertainty, and error). These limits are important benchmarks, and the underlying concepts guide us in how we can reach them. In the first half of the assessment period, the focus has been on communication systems, addressing topics like complexity, interference control, distributed systems and collaboration, storage and caching, automatic control over networks, and coordination, leading to roughly 15 graduated PhD students and more than five active PhD students and postdocs. In the second half of the assessment period, identifying fundamental limits in learning and processing has become a core activity of our research with more than 10 graduated, and more than five active PhD students.

Which communications, processing, and learning strategies allow for an efficient and (close-to) optimal utilization of resources in achieving their task?

In several domains, we have contributed to closing the gaps between the state-of-the-art performance and the ultimate performance limits by providing coding techniques and communication protocols, signal processing and optimization tools, and learning and processing algorithms. Our topics range from massive multiple antenna systems, low-latency/ultra-high reliability protocols, and edge computing in 5G systems and beyond over sensor fusion, compressed sensing, and sparse signal processing to signal processing for biomedical data analysis and automated cell tracking. Overall, more than 15 graduated PhD students and more than ten active students and postdocs have contributed here.

How and under which conditions can we guarantee security, privacy, and trust by design of communications, processing, and learning techniques?

Our approach is based on concepts from information-theoretic security which lead to provably unconditional privacy and secrecy, as well as signal processing methods for intrusion detection and response. We have demonstrated the feasibility and identified fundamental limitations of these concepts in a large number of contexts; e.g., secure communication, smart meter privacy, privacy-preserving learning, privacy-preserving information retrieval and computing, and biometric identification. More than five PhD

students have graduated in this area and more than five PhD students and postdocs are currently active. For the future, we expect all three core research questions to maintain their relevance for our work even though the underlying application domains will shift. An ongoing shift towards more biological and medical systems is already visible.

Composition of the research group, academic sub-disciplines, and benefits from multidisciplinarity

The core of our research lies in the intersection of EE and CS, namely, networking and protocols, communication and information theory, signal processing, and machine learning. Topics like privacy and learning have led to fruitful collaborations and exchanges with researchers from other domains like energy, health, biology, and security. Impact in these domains is only possible if domain competence is involved. As ISE has a strong focus on theoretical research, recruiting analytically strong candidates is a necessity. To expand our recruitment base in the long run, we strive for opportunistically hiring excellent female staff whenever their research interests match our profile.

c. Contributions to the advancement of the state of the art

Fundamental limits in communication, processing, and learning.

We have contributed to **information-theoretic bounds** in relation to wireless communications, covering collaborative transmission over wireless noisy networks, cooperative interference management, approximations using deterministic models, multi-terminal relay networks, interference alignment, and wireless wideband networking.

We have also considered various **source and channel coding** scenarios, with novel extensions such as action-dependent side-information and helper settings with security or privacy requirements. Furthermore, we investigated fundamental performance trade-offs relating to **identification systems**, considering multiple stages, uncertainty, and pre-screening.

We have developed necessary and sufficient conditions for stabilization and **control over noisy networks**, and have also contributed to **networked coordination** problems.

Very recent work considers information-theoretic tools applied to **machine learning**, in particular in the framework of the information bottleneck. We have also developed performance bounds for **distributed optimization** algorithms for time-varying networks.

Algorithms for efficient communication, processing and learning.

Significant efforts have considered **transmission strategies for wireless communications**. We have focused on techniques for large-scale MIMO, such as low-complexity numerical processing for channel estimation, efficient algorithms for joint channel estimation and precoding with hybrid analog/digital hardware, and machine learning approaches for radio resource management. We have also contributed with several results on modeling and mitigating the impact of imperfect radio frequency hardware. We furthermore worked on ultra-reliable low-latency wireless networks and millimeter-wave communications.

We were also active in developing **signal analysis methods of broad utility**. A MIMO system identification method has been included in the MATLAB system identification toolbox since 2013, which makes it widely available to practitioners. Very recently we have also advanced the understanding of information criteria for model selection.

Another important area has been **provably optimal coding scheme**s based on practically feasible coding techniques that allowed us to achieve the theoretical limits in problems like the wiretap channel, cooperative relaying, and anytime communication.

We have also contributed to **image processing** with a focus on 3D / free-viewpoint communication. We advanced the state-of-the-art in tracking 3D objects and streaming given free-viewpoint content in real-time and in a rate-distortion efficient manner, as well as achieving robust transmission over packet networks.

Additional work considers **bioinformatics and medical data analysis**. With co-workers at the Karolinska institute and the SciLifeLab we worked on hidden Markov models for sepsis detection in preterm infants, and for single-stranded DNA sequencing. Also, a joint project with the Blau Lab at Stanford resulted in state-of-the-art multiple target tracking.

Security, privacy, and trust.

We worked on **physical layer authentication** at the air interface of wireless networks. Significant contributions were also made in the area of **privacy-by-design** for cyber-physical systems. To enhance consumer privacy in smart grids, we worked on privacy-preserving energy flow control strategies. We have also considered privacy guarantees in various statistical inference problems. In addition our work on network information theory has in many cases had **secure communication** in the presence of wiretappers as a central goal. More recently we also contributed to the development of **information-theoretic private information retrieval**, in scenarios with colluding servers, adversarial attackers as well as passive eavesdroppers. Finally we have contributed to the development of **explainable AI**, as exemplified by works on structured deep neural network dimensioning and training.

d. Quality and quantity of contributions to the body of scientific knowledge

With more than 470 and 600 peer-reviewed articles published in journals and conference proceedings, respectively, and 63 graduated Ph.D. theses, ISE has produced an impressive amount of high-quality research publications during the assessment period. The following publications are samples that we would like to highlight for their high quality:

Fundamental limits

S. Schiessl, J. Gross, M. Skoglund und G. Caire, “Delay Performance of Multiuser MISO Downlink under Imperfect CSI and Finite Length Coding,” IEEE JSAC, April 2019
First work that characterizes the joint impact of queuing and channel coding delay in intra-cell downlink transmission, under the important practical assumption that some delay needs to be permitted for channel training and taking into account errors due to imperfect CSI.

A. A. Zaidi, T. J. Oechtering, S. Yüksel and M. Skoglund, "Stabilization of Linear Systems Over Gaussian Networks," in IEEE Trans. Automatic Control, Sept. 2014.
First comprehensive theoretical bounds that predict whether a linear system can be stabilized over a noisy wireless network, relating stabilization to the necessary amount of directed information flow.

R. Timo, T. J. Oechtering and M. Wigger, “Source Coding Problems With Conditionally Less Noisy Side Information,” in IEEE Trans. Inform. Theory, Sept. 2014.
Introduction of new class of side information and derivation of optimal rate-distortion regions considering fundamental distributed source coding settings as a result of a series of collaborative works.

M. Maros and J. Jaldén, “On the Q-linear convergence of Distributed Generalized ADMM under non-strongly convex function components,” IEEE Trans. Signal and Inf. Proc. over Networks, Oct. 2019.

Recent mathematical paper with a strong contribution. The paper relaxes the conditions previously needed to prove linear convergence of one of the most popular algorithms for distributed optimization to date.

Algorithms

Z. Si, R. Thobaben, and M. Skoglund, "Bilayer LDPC convolutional codes for decode-and-forward relaying," IEEE Trans. on communications 61 (8), 3086-3099, 2013.
This paper illustrates nicely how achievable schemes from the information theory literature can be lifted by using coding theory. It also provides new insights into the design of nested codes in general.

A. Owrang and M. Jansson. A model selection criterion for high-dimensional linear regression. IEEE Transactions on Signal Processing, 66(13):3436 – 3446, July 2018.
The paper extends the classical information criteria for model selection, like BIC, to also handle problems when the number of regressor variables is larger than the number of measurements, or situations where the models are not nested.

L. Zhang, J. Liu, M. Xiao, G. Wu, S. Li and Y. Liang, "Performance Analysis and Optimization in Downlink NOMA Systems with Cooperative Full-duplex Relaying," IEEE JSAC, Oct. 2017.
This work is an early contribution to full-duplex relaying for NOMA. The paper is WoSHighly Cited.

H. Ghauch, T. Kim, M. Bengtsson, and M. Skoglund, "Subspace estimation and decomposition for large millimeter-wave MIMO systems," IEEE J. Selec. T. Signal Processing, vol. 10, no. 3, pp. 528-542, April 2016.
The paper introduces one of the main state-of-the-art solutions for hybrid analog/digital implementations for massive MIMO, especially considering the combination of channel estimation and precoding design.

K. E. G. Magnusson, J. Jaldén, P. M. Gilbert, and H. M. Blau, "Global linking of cell tracks using the Viterbi algorithm," IEEE Trans. Medical Imaging, April 2015.

This paper has a major impact outside of our field and represents a collaboration with Stanford researchers. The algorithm described is the basis for our contribution to two Nature methods papers.

Z. Ma, P. Kumar Rana, J. Taghia, M. Flierl, and A. Leijon, "Bayesian Estimation of Dirichlet Mixture Model with Variational Inference," Pattern Recognition, Sept. 2014.
Notable example for a contribution to basic learning theory.

N. Shariati, E. Björnson, M. Bengtsson, and M. Debbah, "Low-complexity polynomial channel estimation in large-scale MIMO with arbitrary statistics," IEEE J. Select. T. Signal Processing, Oct. 2014.
The paper was one of the earlier papers on low-complexity numerical algebra solutions for massive MIMO applications.

Security, privacy and trust

Q. Wang and M. Skoglund, "Symmetric private information retrieval from MDS coded distributed storage with non-colluding and colluding servers," IEEE Trans. on Inform. Theory, Aug. 2019.
An early contribution to the recent interest information-theoretic private information retrieval. Together with the corresponding conference versions the work received more than 100 citations in less than 2 years.

K. Kittichokechai, Y.-K. Chia, T. Oechtering, M. Skoglund and T. Weissman, "Secure source coding with a public helper," IEEE Trans. on Inform. Theory, July 2016.
The paper solves the problem of secure source coding with an honest but curious public helper (for example an unencrypted packet over the Internet). A collaboration with Stanford.

e. Engagement in national and international research collaboration within academia

Type of collaboration: J = one or a couple joint journal papers; JM = multiple joint journal papers; P = one or a couple joint projects (externally funded); PM = multiple joint projects (in the period 2012-2019).

The following are our **most important international academic collaborations:** Princeton University: H. V. Poor (JM); Stanford University: T. Weissman, A. El Gamal, B. Murmann, H. Blau (JM); MIT: M. Medard (JM); UC Berkeley: I. Stoica (JM); UI Urbana-Champaign: S. Hutchinson, Y. Bresler (JM); Univ Minnesota: N. Sidiropoulus, S. I. Roumeliotis (JM); Carnegie Mellon: M. Satyanarayanam (JM); Univ. Texas Austin: T. Tanaka (JM); Univ. Maryland: J. Baras (J,PM); UCLA and EPFL: A. H. Sayed (JM); ETH Zurich: G. Hug (PM); Imperial College London: D. Gunduz (JM,PM); Queens University, Canada: F. Alajaji and S. Yuksel (JM)

We in addition highlight the following collaborations: Univ. Notre Dame (J); Univ. North Texas (JM); Purdue (J); TU Berlin (JM,P); TU Munich (JM); TU Dresden (JM); RWTH Aachen (JM,PM); Univ. Paderborn (J); Fraunhofer HHI (P); Vienna Univ. Tech. (JM); NSERG Grenoble (JM); Telecom Paris (JM); Université Paris Seine

(JM); University of Lyon and University of Saint Etienne; EURECOM (JM); Univ. Luxembourg (P); Delft University (JM); Hasselt Univ. (P); NTNU (JM); Beijing Univ. Post and Telecom (JM); SWJTU (JM,P); Chinese Univ. Hong Kong (JM); Sharif (JM); Bilkent University (JM); Univ. Sydney (J)

Our **most important national collaborators**: Uppsala University: P. Stoica, D. Zachariah, C. Wählby, T. Schön (JM,P); LiU: E. G. Larsson (JM,PM); Karolinska: E. Herlenius, B. Önfelt (PM,JM)； University of Gävle: N. Björsell, D. Rönnow (JM,PM)； Chalmers: E.G. Ström, H. Wymeersch (JM)；Lund: E. Gudmundsson, A. Jakobsson (J)

f. Follow up from previous evaluations

In 2012 the Division was evaluated under the Unit of Assessment (UoA) 2.1., "Information Processing, Networking and Control." Encouraging feedback received in the final report includes: "The research program is of the highest quality; it has the potential of high impact and is conducted in an environment that is vibrant and conducive to high morale, motivation, and productivity." We have embraced the positive feedback received and taken it as evidence that we were already on the right track. Since 2012 we have therefore continued working based on the same principles for excellence, quality and collaboration.

3. Viability

a. Funding; internal and external

The division has ongoing projects funded by the Swedish Research Council (VR), H2020 including the ERC, the Swedish Foundation for Strategic Research (SSF), The Knut and Allice Wallenberg (KAW) Foundation, Wallenberg WASP, MSB and Vinnova. SSF and KAW provide most of their funding through 5-5-5 type of projects, that is "5 PIs, over 5 years, with a budget of 5 Mkr per year." Both SSF and KAW however also provide personal career award grants. VR and the ERC focus on the individual researcher and offer single-PI initiated projects as well as individual career awards. The EU framework programs, as well as VINNOVA, focus on multiple PI projects in collaboration with industry and society. Main observations since 2012 include: The competition to receive a grant for a PI-initiated research project from VR has increased significantly. Since the only other source for such grants is the ERC, where the competition was already fierce (0 to 2 projects to KTH per year), the prospect that even very talented researchers can secure an external grant to fund basic research has decreased since 2012; VINNOVA and the EU (non-ERC) are looking less and less at academic excellence when granting funding, and external factors that are very hard for the individual researcher to control have increased in significance.

b. Academic culture

The division has a tradition of fundamental research best described as applied mathematics, with contributions to information theory, signal processing, and communications. We share notions of quality such as an appreciation of mathematical rigor and clarity. The culture is passed on to Ph.D. students within the division by their respective academic advisors, who in turn share values at faculty meetings and with their scientific international peers. As noted previously, most faculty take part in forming notions of quality through, for example, associate editor appointments with top journals within their respective fields. Notions of quality are further shared via frequent joint publications involving several faculty members and during monthly division faculty meetings.

Ph.D. students present their work weekly to fellow Ph.D. students within the division at a weekly lunch seminar, allowing older Ph.D. students to provide examples of high-quality work to their younger peers.

c. Current faculty situation

The Division hosts 8 Full and 4 Associate Professors. We also host one affiliated faculty (employed by ABB) and one adjunct professor (employed by Ericsson). The regular full professors were born in 1961, 65, 67, 68, 69, 75 (2), 76 and the associate professors in 1971, 75, 77 (2). We can thus expect only one retirement in the next 10 years. Then another 4 retirements can be expected in the interval 2030-40. We conclude that there is no near-time need for recruiting junior faculty to balance for coming retirements.

All faculty members are men, even though we succeeded on two different occasions to get a woman candidate top-ranked and subsequently offered the position. Unfortunately, the woman top-candidate declined our offer on both occasions, for (family) reasons beyond our reach. Recognizing the challenging general male/female distribution in our area of research and education, we continue our efforts to actively recruit and engage top women talents.

Overall, the Division has filled several new faculty positions in the period since 2012. This has resulted in a renewal of the faculty and in a significant broadening of our expertise.

d. Recruitment strategies

We advocate *competency-based recruitment*. PhD students and postdocs are hired following this principle, where the hiring faculty first sets the desired competences and then searches for evidence on those competences. Positions are internationally announced or opportunistically when excellent PhD student or Postdoc candidates communicate their interest and sufficient funding is available. An extra effort in finding sufficient financial resources is done if excellent women candidates communicate their interest. Excellent students from KTH are pro-actively informed about the opportunities at our division. We were accordingly very successful in the competitive excellence program of the EE doctoral school hiring the most excellent PhD students.

e. Infrastructure

See IS level description in section 2.1.

4. Strategies and organization

a. Goals for development 5–10 years ahead

Our focus on fundamental research grounded in applied mathematics creates ample opportunity to contribute to a wide range of applications. Our solid base makes it easier for us to adapt to trends in what applications are “hot” compared with more applied researchers whose base is in the application itself and not in the foundations. In 5-10 years our expertise and activities will reflect the full spectrum of information science, from machine learning and statistics, via biomedical data analytics to the networked society. We will have established several new collaborations with societal partners in urgent need of expertise in data science and security/privacy for their research. We will always have sustainable development in mind when choosing which application areas to focus on.

In 5-10 years we will have contributed significantly to the development of 6th generation wireless systems. We will also have established cyber-physical-human systems, with

humans as active decision-making agents in the network as one of our main fields of research. Our interest in information theory will in addition have contributed to the analysis and interpretation of various machine-learning techniques. A particular goal is that we will have established multiple results in the theoretical understanding of deep learning.

Our view is that our existing faculty members represent the main directions where we plan to be present, with one exception: quantum information. While the division already offers a PhD level course in quantum information theory, we believe that an externally recruited faculty member will significantly strengthen our ability to compete for funding in the area.

b. Congruence with university-level goals for research as set out in "A leading KTH - Development Plan 2018-23" and with the school(s) development plan(s) respectively.

The division is already internationally competitive, in line with stated goals in KTH's plan. Our research is disseminated in the top international journals and top conferences with the fields of information theory, signal processing, and communications. The fields covered by the division are traditionally categorized as electrical engineering (EE), a subject area where KTH is ranked as the 17th best university worldwide by QS in 2020.

The EECS development plan from 2018 targets increased collaboration. The division has since 2018 engaged one adjunct professor with Ericsson, significantly increased the number of industrial Ph.D. students, and continues to participate in projects with industry. To contribute to systematically explaining how our research contributes to solving societal challenges. Faculty in the department have taken on the role of impact leader within EECS and participated in national efforts for popular scientific research communications.

c. Leadership structure and collegial structure

The Division is headed by the Division Head (Skoglund) with a Vice-head (Jansson) as stand-in. The main interface toward the Department when it comes to undergraduate teaching is the Teaching Coordinator (Jansson). The Division is not formally divided into smaller units below the level of Division. Our research and research education is however informally coordinated in research groups, headed by a faculty member and consisting of that member's PhD students and postdocs. The senior faculty members meet at least once per month to discuss cross-group and KTH issues. We also strive to organize one senior faculty retreat per year where we discuss strategic issues and plan for the future. Overall we thus promote a flat organizational structure, where individual responsibility is crucial. We also strive to foster collaboration and joint efforts among faculty members.

d. Strategies for high quality

ISE faculty has a common understanding for high quality research, maintained through discussions between faculty, PhD students, post-docs, and colleagues. Our ambition is to pursue excellent research of the highest international level, and compete with the most excellent researchers in the world. Many of our PhD students spend an extended period of time at another university during their PhD. We invite prominent experts in the field as faculty opponents for our PhD defenses. We encourage reproducible research, by publicly sharing implementation code, e.g. on github, and data related to our publications as well as making papers online available on our own homepages or arXiv.

An instrument for quality assurance is the mandatory weekly large lunch seminars where every PhD student and postdoc on a yearly basis present their current research to the whole division. The supervisor of the presenter acts as session chair with the task to

establish a discussion with a broad participation. The PhD student receives written feedback from their peers on their problem formulation, research results, and presentation. This communicates an expected quality standard.

5. Interaction between research and teaching

The ISE faculty members are active in teaching basic and advanced courses, project courses, and degree projects at first and second cycle as well as PhD courses, and take leading roles in the organization and coordination of education programs at EECS (e.g., program directors for the 5-years program in EE and the 2-years MSc. program in Information and Network Engineering; degree project coordination across the Machine Learning, System, Control, and Robotics, and Information and Network Engineering programs). All this provides ISE with good opportunities for interaction between research and education. Given the division's strong track record in the fundamentals of EE, it is also comparatively well-represented at the Bachelor's level where its faculty teach three basic courses within the area of signals and systems. Our research provides our teaching with important context (e.g., motivating examples, trends, and culture of the research community), and the progressive structure of our courses from basic and advanced courses over project courses to degree projects allows us to increasingly steer our students from the very fundamentals to cutting-edge research. At PhD level, our courses are entirely tailored to the research needs of our students, continuously updated, reinvented, and created from scratch as necessary.

6. Impact and engagement in society

See IS level description in section 2.1.

2.5. The Division of Decision and Control Systems (DCS)

Website: https://www.kth.se/dcs

DCS has over the last 10-15 years developed into one of leading groups in automatic control world-wide. Its scientific and technological influence is well documented by pioneering contributions to the field, many high-impact research results, several successful applications in a number of business sectors, and various international recognitions and leaderships as detailed below.

1. Overall analysis and conclusion; strengths and development areas (1 page)

a. Limited SWOT-analysis

Research

Strengths: DCS comprises several strong research groups with complementary expertise and with high success in securing external competitive research funding. We have strong publication record in terms of volume, impact and presence at prestigious venues. The faculty, PhD students, and postdocs are almost exclusively recruited from outside of KTH and has a good balance between Swedish and other nationalities. The division maintains a large national and international network in academia and industry.

Weaknesses: The industrial and societal need and interest in the DCS domain is large and rapidly growing. A potential weakness is the limited size of the faculty and thereby its ability to serve Swedish industry and society.

Organization

Strengths: Flat organization characterized by collegiality, transparency and positive team spirit. Faculty members hold essential leadership positions in various organizations at KTH, in Sweden and in the international scientific community.

Weaknesses: Poor gender balance on faculty level and to some extent on PhD student and postdoc levels. Need for more junior faculty; currently no assistant professor in the division.

Important future development areas:

We plan to continue to strengthen and enhance our signature research areas, including networked control, robotic and autonomous systems, optimization and control, machine learning, cyber-physical security, transportation and vehicular systems, and process modeling and control. In the near future, we see significant possibilities to expand our activities in cooperative autonomous systems, machine learning for control, and other core topics of digitalization and automation at large. Part of this development will come through the recruitment of junior faculty and new cross-disciplinary collaborations in conjunction with the WASP and Digital Futures initiatives.

b. Summary statement on contributions of department on impact, infrastructure and sustainable development

Decision and control systems are pervasive and appear practically everywhere: in our homes, in industry, in scientific instruments, in all types of vehicles and infrastructure systems. They improve resource efficiency and robustness of individual devices as well as of industrial plants and large infrastructures. Enhancing the way computers are able to coordinate and control man-made systems is without doubt a key technology for sustainable development, and as 5G, cloud and IoT communication and computing capabilities is becoming pervasive, control technology is of growing societal importance.

Contributions to impact:

DCS researchers have made many fundamental scientific contributions, some of which have also had major influence on application domains. Some key contributions can be illustrated by how our research has been featured on the front page of IEEE Control Systems Magazine over the last few years: DCS has made pioneering contribution to the development of an intelligent goods road transport technology based on semi-automatic truck platooning, currently being implemented and evaluated by most major truck manufacturers world-wide. The division established the area of cyber-physical control systems security together with other academic and industrial research groups about a decade ago. The importance of the development of fundamental principles and algorithms for wireless networked control systems by DCS researchers has been demonstrated in several applications, most recently in a case study at the Iggesund paper mill illustrating how plant-wide wireless sensor and actuator networks can be integrated into industrial processes.

Most of our PhD students take up industry positions in Sweden or abroad after graduation. We have a large number of former students and postdocs at Scania and Ericsson, but also in other companies such as Bosch, DENSO, Electrolux, Google, HERE, Honeywell, Lyft and Mathworks, to name a few, illustrating the diversity of the uptake. Among former PhD students we have the Head of AI Technologies at Scania, the Director of Platform Software at Tobii and the software architect behind the recent series of robotic vacuum cleaners from Electrolux. In addition, over 50 former PhD students and postdocs have continued with successful academic careers and secured faculty positions in top universities in America, Europe, Asia and Australia. Examples of current affiliations on these continents include University of Texas at Austin and University of Pennsylvania; University of Manchester; University of Grenoble; Supelec; KAIST; Tsinghua University and Tokyo Institute of Technology; and University of Melbourne (2) and University of Sydney. In the Nordic countries with have for instance faculty members at KTH, Lund University, Uppsala University, University of Copenhagen and Norwegian University of Science and Technology.

2. Research profile

DCS is one of the leading groups in control, as for instance indicated by consistently high ranking for KTH in Automation and Control in Shanghai Ranking's Global Ranking of Academic Subjects (2017-2018-2019 ranked 12-15-19). The division comprises an internationally well-recognized team with scientific excellence and proven leadership abilities. The scientific production and impact are comparable with top research groups world-wide. Faculty members are regularly invited to give keynote speeches and plenary talks at the leading international conferences. They hold several leading positions in international scientific organizations and agencies.

The DCS scientific impact is high. To exemplify, consider the two leading archival journals in the area of automatic control: Automatica and IEEE Transactions of Automatic Control. It can be noticed that KTH is the 6th largest contributor to both Automatica and IEEE Transactions of Automatic Control over the last few years. (The largest contributor is CNRS and University of California, respectively.) Over the time period of the RAE, DCS has contributed with the fourth and eleventh most cited Automatica paper, as well as the tenth most cited paper in IEEE Transactions on Automatic Control.

The faculty has been able to secure a high level of external research funding from the European Commission and national Swedish funding sources. In addition to a wide range of framework and project grants, funding includes large 5-10 year individual excellence grants from VR (Distinguished Professor and Consolidator grants), ERC (Consolidator and Starting grants) and Knut and Alice Wallenberg Foundation (Wallenberg Scholar and Fellow grants).

a. General information of the division

The division currently comprises 93 personnel, composed of 11 faculty, 21 postdocs, 55 PhD students and 6 researchers. Of the faculty, eight are full professors, two are associate professors and one is adjunct professor.

b. Central research questions and themes, knowledge gaps addressed, main research activities and composition of research team(s)

The division performs research in the broad area of automation and control, learning and decision-making. In particular, our expertise is centered around networked control and

robotics; machine learning; cybersecurity; optimization and control; control of transport systems; system identification; processing modeling and control.

c. Contributions to the advancement of the state of the art within the research fields of the department

The main scientific contributions of DCS research groups are in the following areas.

Networked control.

Wireless networked control systems emerged from the successful hardware and software developments of wireless sensor and communication networks. These control systems, with spatially distributed sensors and actuators, have to potential to drastically improve system robustness, performance, and resource efficiency. As the wireless communication medium imposes control loop imperfections, such as message delays and dropouts, appropriate modeling and analysis tools need to be developed, together with new control architectures and principles able to handle the uncertainty but also benefit from the additional flexibility. Several faculty members have contributed extensively over the last 10-15 years to this area of research and a large number of prestigious awards and research grants have been received for the work.

Representative publication:

J. Wu, Q.S. Jia, K.H. Johansson, L. Shi, Event-based sensor data scheduling: Trade-off between communication rate and estimation quality, IEEE Transactions on automatic control 58 (4), 1041-1046. (296 citations in Google Scholar)

Cybersecurity. Cybersecurity in control systems is a new, rapidly evolving research field. The practical motivation comes from concerns of malicious cyberattacks against large-scale networked control systems, such as critical infrastructures (power systems, etc.). DCS has contributed with cyber-physical security metrics to localize inherent infrastructure weaknesses, and to methodology for attack-resilient monitoring and controller design. Much of the cybersecurity work is conducted within the framework of the Center for Resilient Critical Infrastructures (funded by the MSB, led by DCS), and within the Trust area of KTH Digital Futures.

Representative publication:

A. Teixeira, I. Shames, H. Sandberg, K.H. Johansson: "A secure control framework for resource-limited adversaries", Automatica 51, 135-148, 2015 (461 citations in Google Scholar)

Multi-robot systems. Robotics research involves theory and application for autonomous (multi-agent) systems task planning and control in unknown and dynamic environments. The considered platforms include mobile robots which may be also manipulator endowed, aerial vehicles and underwater robots. Further application domains include human-machine-interaction and social networks. The developed theoretical results involve elements from nonlinear and robust control, decentralized systems, hybrid control and formal methods for controller synthesis. The research in this domain is sponsored by a number of EU (ERC, H2020, FP7) and national projects (KAW, VR, Vinnova, SSF).

Representative publication:

D. V. Dimarogonas, E. Frazzoli and K. H. Johansson, Distributed event-triggered control for multi-agent systems, IEEE Transactions on Automatic Control, Vol. 57, No. 5, pp. 1291-1297, May 2012. (1198 citations in Google Scholar)

Optimization and decision-making. With the ease of connecting devices to sense, analyze and control the environment, there is an increased interest in developing technology for coordinating large distributed systems to save resources while guaranteeing a desired performance. It is natural to view this coordination as an optimization problem and develop coordination mechanisms based on principles from distributed optimization. Examples include matching consumption and production in smart grids, managing radio resources in wireless networks and performing machine learning on large distributed data sets. The DCS faculty has contributed to several fundamental aspects of multi-agent, distributed and large-scale optimization, both in terms of new theory for asynchronous and communication-efficient computations, and in terms of novel optimization algorithms with strong performance guarantees.

Representative publication:

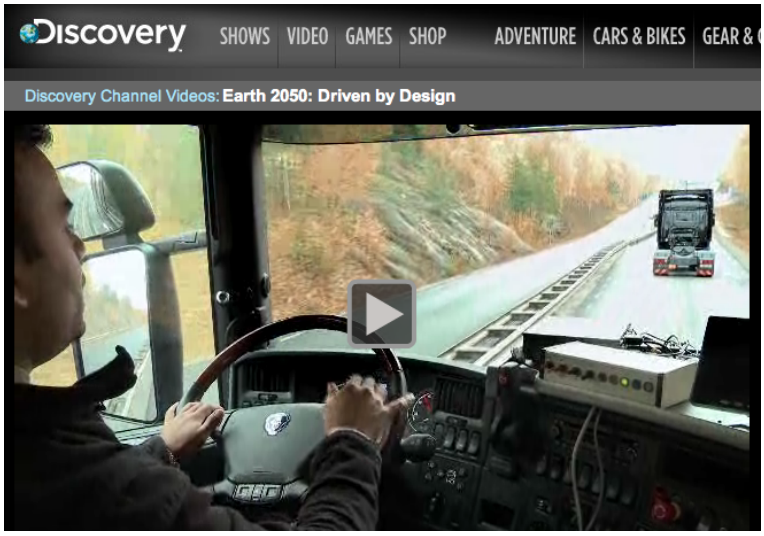
E. Ghadimi, A. Teixeira, I. Shames and M. Johansson, Optimal parameter selection for the alternating direction method of multipliers (ADMM): quadratic problems, IEEE Transactions on Automatic Control, Vol. 60, No. 3, pp. 644-658, March 2015. (328 citations in Google Scholar)

Machine learning.

In ML, the main activities at DCS concern areas at the intersection of control and learning theories. Specifically, we develop theoretical tools towards the foundations of reinforcement learning (RL), including the so-called bandit optimization, and their application to iterative identification and control problems. A particular emphasis is on model-based RL where an a-priori knowledge on the dynamical systems to be learnt, e.g. through its structure, may considerably speed up the learning process. Most of our work deal with systems with large but finite state and action spaces, with applications such as the design of search engines, resource allocation in networks in mind. However, recently, we have been revisiting RL problems of more classical linear systems continuous state and action spaces. Other important activities at DCS aim at deriving information-theoretical limits and efficient algorithms in clustering and change-point detection problems.

Representative publication:

J. Ok, A. Proutiere, D. Tranos, Exploration in Structured Reinforcement Learning, NeurIPS 2018 – oral presentation. (13 citations in Google Scholar)



DCS research on intelligent transportation and former industrial PhD student featured in a series on future transport by Discovery Channel.

Intelligent transport. Members of DCS study many applications of connected and automated vehicles and transport systems, where we apply methods from classical, optimal and model predictive control, but also learning-based algorithms and graph-search methods. The research is applications-driven and we collaborate extensively with automotive and telecom industries (Scania, Ericsson). Contributions include longitudinal and lateral vehicle control, collaborative and coordinated control of vehicle platoons, motion planning, and routing and coordination of vehicle fleets,

Representative publication:

A. Alam, B. Besselink, V. Turri, J. Mårtensson, K.H. Johansson: "Heavy-duty vehicle platooning for sustainable freight transportation: A cooperative method to enhance safety and efficiency", IEEE Control Systems Magazine 35 (6), 34-56 (157 citations in Google Scholar)

System identification and process modeling.

System identification is a very strong research field within DCS, where several subtopics have been intensely studied, including input and experiment design, estimation under sparsity and low rank constraints (using convex and non-convex heuristics), kernel regularization and continuous-time identification. In addition to the problem of estimating linear and nonlinear dynamic models, at DCS we have also developed tools for the efficient estimation and control of hidden Markov processes and for inverse filtering and control, where the goal is to reverse engineer an existing agent acting on a Markov decision process. We have also developed applications of system identification in several fields, including medical research, bioproduction, and paper making.

Representative publication:

M. Annergren, C. A. Larsson, H. Hjalmarsson, X. Bombois and B. Wahlberg, "Application-Oriented Input Design in System Identification: Optimal Input Design for Control [Applications of Control]," in IEEE Control Systems Magazine, vol. 37, no. 2, pp. 31-56, April 2017. (23 citations in Google Scholar)

d. Quality and quantity of contributions to the body of scientific knowledge

The division aims at publishing at the most prestigious venues in their respective field. In some areas, these are journals published by the IEEE, SIAM or Elsevier; in other areas, notably machine learning, the most prestigious venues are conferences.

Since 2013, more than 20 publications from the department have surpassed the 100 citation mark. These papers span diverse topics such as networked control, smart grids, transportation systems, optimization, robotics and planning, cybersecurity and wireless systems. In the area of machine learning, we have a continuous presence at top venues such as NeurIPS, AISTATS and ICML; and several times, the division has contributed more than 50% of all accepted papers from Sweden at these conferences. We have received recognition in terms of several best paper awards in journals and conferences since 2013, including the Best Applications Paper Award from IEEE Transactions on Automation Science and Engineering, best paper award from IEEE Conference on Communications, and best student paper awards from IEEE CCTA and IEEE ICASSP.

In a recent bibliometric study by ICT-TNG covering the years 2010-2018, 480 publications from DCS were recorded. 146 papers appeared in the 20% most frequently cited journals in corresponding Web of Science categories. Out of them, 7 publications were among the 1% most cited, 31 among the 5% most cited, and 51 among the 10% most cited papers. In this period, DCS obtained an average visibility score (Jcf-score) of 1.97 and the impact score

(Cf-score) of 2.43. This can be compared to the ICT TNG as whole, which obtained the Jcf-score 1.73 and the Cf-score 1.79. In the same bibliometric study, out of the 20 publications with the highest impact score, 9 had DCS affiliated authors.

DCS faculty members are regularly invited to give keynote presentations and plenary talks. Recent examples include IEEE Conference on Control Technology and Applications; IEEE International Conference on Control and Automation; IFAC Workshop on Control of Transportation Systems; IFAC Symposium on Robust Control Design; ACM MobiHoc; ITA; Chinese Control and Decision Conference; European Control Conference; International Conference on Control, Automation and Systems; IEEE Multi-Conference on Systems and Control; Chinese Control Conference; IFAC Workshop on Distributed Estimation; WiOpt; Control in Networked Systems (NECSYS); Balkancom, ISWSC and Lunteren Conference

Another aspect of our research is to maintain deep long-term collaborations with key industries in the Stockholm region, such as Scania, Ericsson and ABB. This has resulted in joint publications, projects, patents and knowledge transfer in both directions. For example, our joint work with Scania has led to close to 100 papers and patents, several with high impact. Today, four faculty are advising industrial PhD students working for Scania, over 20 of our PhDs and postdocs have taken up positions with Scania. With Ericsson, our long-term relationship has enabled Dr Gabor Fodor to become an adjunct professor at our division, and led to multiple projects, publications and patents. 10 PhDs and postdocs from the division are currently working at Ericsson. These collaborations were instrumental in the creation of the Integrated Transport Research Lab (ITRL) which has been funded with 50MSEK by Scania and 15MSEK by Ericsson during 2014-2021.

e. Engagement in national and international research collaboration within academia and its outcomes

The division is playing a leading role in several national and international research programs and local initiatives at KTH.

DCS has developed KTH Smart Mobility Lab, which comprises a large set of heterogeneous autonomous miniature vehicles, a motion capture system, a wireless communication infrastructure, real-time integration of traffic data, and a variety of user interfaces on both vehicle and operator levels. The lab is financially supported by KTH, Scania, and Ericsson, and is linked to the Integrated Transport Research Lab, which is co-directed by a DCS faculty members.

The Wallenberg AI, Autonomous Systems and Software Program (WASP) is a major national initiative for strategically motivated basic research, education and faculty recruitment in artificial intelligence, autonomous systems and software development. WASP was initiated in 2015 .The ambition is to advance Sweden into an internationally recognized and leading position in these areas. The starting point for WASP was the combined existing world-leading competence at Sweden's five major ICT universities: Chalmers University of Technology, KTH Royal Institute of Technology, Linköping University, Lund University and Umeå University. The research at DCS was one of the corner stones of WASP and DCS faculty has been part of the program management of WASP since the very start, chairing the WASP International Management Group and being responsible for WASP KTH. WASP funds over 70 PhD students at KTH and ten new faculty positions. The DCS is very active in WASP and has 20 PhD students and 5 Postdocs sponsored by the program.

KTH has been tasked by the Swedish Government to establish a strategic research environment for interdisciplinary research on the future technology for digitization. KTH Digital Futures was accordingly established 2020 with a base funding of about 115 MSEK per year. DCS has taken several leading roles in the preparation and execution of the new environment and is heavily involved in developing the research program. To be integrated with KTH Digital Futures, Digital Demo Stockholm is a unique collaboration between the City and Region of Stockholm, KTH, Ericsson, ABB, Scania, Skanska, and Vattenfall. The collaborations departure point is the City of Stockholms Vision 2040. The goal is to show and demonstrate digital solutions that could help Stockholm to develop and make life better for its inhabitants. DCS faculty members have been driving the development of DDS and the increased societal impact of digitalization research at KTH.

- Faculty members of DCS are taken many leadership positions to serve the international scientific community and the research society in general. Examples of positions currently held include Vice President of the European Control Association, Chair of the ERC Consolidator Grant Panel on Systems and Communication Engineering, Chair of the IEEE Control Systems Society Fellow Nominations Committee, Scientific Council for Natural and Engineering Sciences with the Swedish Research Council, Chair of the IFAC Awards Committee, Chair of the Swedish IFAC National Member Organization, Member of the Portfolio Board for Natural Science and Rechnology for the Norwegian Research Council.

The DCS faculty includes Fellows of IEEE, IFAC, and IVA, and also an IEEE Control Systems Society Distinguished Lecturer.

3. Viability

a. Funding; internal and external

The division is currently supported by external grants from the EU and all major national funding agencies (Swedish Research Council [VR], Swedish Foundation for Strategic Research [SSF], Swedish Innovation Agency [VINNOVA], Knut and Alice Wallenberg Foundation [KAW], Swedish Civil Contingencies Agency [MSB], Swedish Energy Agency). Our total funding for research is 81 MSEK per year (2019). Out of this, 33% is internal faculty funding, and 67% is external funding. Today, eight out of eleven faculty members have competitive individual grants for basic research from VR, and several faculty members have received larger prestigious individual research grants such as KAW scholars and

fellows, VR 10-year distinguished professor grants and research environment grants, as well as ERC starting, consolidator and advanced grants. We have a high success rate in larger framework grants from SSF, VR, KAW and MSB, as well as from the European Commission. Several of these projects were led by DCS faculty, including RECONFIG and Co4Robots. During the last few years, we are running an increasing number of industrial PhD student projects with companies such as ABB, Scania, Ericsson, Elekta and Toobi.

b.Academic culture

The division of Decision and Control Systems has a strong tradition of fundamental research in automatic control, system identification, optimization and machine learning. We have a common view of quality, with a focus on mathematical rigor and engineering relevance. We strive to pursue research of the highest international quality and aim at continuously expanding the frontiers of research.
The faculty is visible internationally and takes an active role in the international community in terms of e.g. *International Conference organization*: IFAC World Congress 2020 (Technical Associate Editor), ECC 2020 (Tutorials and workshop chair), ECC 2019 (IPC chair), IEEE CDC 2019(IPC Vice-chair for tutorial sessions), NeurIPS (Area chair), COLT 2018 (Local chair), SYSID 2018 (General chair), IFAC WC 2017 (Associate area editor) IFEEE CASE 2015 (Special session chair), IFAC WC 2014 (Technical associate editor), 2013 ECC (IPC co-chair) *Editorial Board membership (figures indicate number of faculties involved):* Automatica (Associate editor x 4), L-CSS (1), Editorial Committee for Annual Review of Control, Robotics, and Autonomous Systems (Editorial committee member), ACM Transactions on the Internet of Things (Editorial board), IEEE Transactions on Information Theory (Associate editor) IEEE Transactions on Control of Network Systems (Senior editor, associate editors x2), European Journal of Control (Editorial board member) and *Society leadership* detailed in Section 2.e.

In a similar way, we encourage students and postdocs to be active and participate in review processes and the organization of conferences and workshops.

We have a flat organization with research groups centered around individual faculty, and several constellations which involve multiple research groups with common or related research (e.g. in networked control, system identification, transportation and machine learning). Seminars, study groups and research project meetings are organized in these constellations (but open to all DCS personnel) to enable sufficient technical depth.

c. Current employment situation

The department is a diverse and international environment. In the faculty, 6 out of 11 are Swedish born. Among the PhD students, 73% are international, and among the postdocs the corresponding number is 100%. Even though the division has shown a strong growth in both teaching and research, the faculty has remained the same since 2012 and the majority are now full professors. The division would benefit from renewal of new junior faculty.

DCS positively contributes to the equality and diversity work at KTH. Information and communication technology is an area in general strongly dominated by men both at university and in companies. This is the largest challenge for equality and diversity. Typically, the proportion of female researchers and students is around 10–15%; at DCS, the faculty is currently all male, 20% of the PhD students are female, and 14% of the postdocs are female. These numbers must increase in the future and we believe that the

continuous mapping of talented female students and researchers in all recruitment campaigns has the potential to do this. Fortunately, the division has an excellent research network with several leading women researchers; role models include Profs. Sandra Hirche (Technical University of Munich), Na Li (Harvard University), and Claire Tomlin (UC Berkeley). Our experience shows that an inter-disciplinary research theme, such as the proposed one on human-robot cooperation, might attract female students. We have recently increased the attention on recruitment of female PhD students and postdocs.

d. Recruitment strategies

We work actively to identify, motivate and foster strong students in our different programs. Notable initiatives include the SURF undergraduate internship program with Caltech, our DCS summer research internship program and part-time employment of students as lab assistants and research engineers during their studies. We also use our extensive international network of collaborators in academia and industry to recruit PhD students and postdocs.

e. Infrastructure and facilities

See IS description level description in section 2.1.

4. Strategies and organization

a. Goals for development 5–10 years ahead

The strategy of the division has always been to recruit talented and driven faculty with complementary expertise, and then give them the best possible conditions to excel in research, teaching and interaction with society. This organization has worked very well in the past: we have been able to adapt to changes in the funding landscape and been able to rapidly build up substantial research in emerging areas (e.g. cybersecurity and theoretical machine learning). We now focus on recruiting junior faculty to keep up this momentum so that KTH can remain its international leadership in automation and control.

b. Congruence with university-level goals and the school(s) development plan(s)

The division has played an active role in strategy work on the department and school level, as well as strategy work in larger research constellations such as WASP and Digital Futures.

c. Leadership structure and collegial structure

The division has a transparent and inclusive leadership style. Information is shared with all faculty and critical strategical decisions are discussed in monthly faculty meetings. These meetings are scheduled prior to department and school executive committee meetings, to ensure that the faculty can influence the division input to important decisions. The entire division meets on Friday afternoons, discussing all aspects of academic life, while the most technical aspects of research are discussed in research group meetings, organized around one or several faculty, as well as in topical study groups and division-level seminars.

d. Strategies for high quality

Scientific quality, creativity and innovation is deeply ingrained in the division culture. We encourage and appreciate research investments that can lead to high impact results, while we attempt to maintain a strong and continuous presence at the most prestigious

conferences and journals in our field. Bibliometry is used as a quantitive indicator to ensure that our strategy works.

5. Interaction between research and teaching

DCS teaches 2 courses at the BSc level and 7 courses at the MSc level, with a total of about 1000 students per year. We work continuously on improving existing courses, updating them with motivational examples from the latest research, and creating brand new course offerings. Since 2015, we have introduced MSc courses in model predictive control and reinforcement learning. These courses are very popular: in particular, the last offering of the reinforcement learning course attracted more than 200 participants.

About 40 students complete their Master's degree project at the division each year, of which many are directly involved in the research projects of the division. DCS also have student exchange programs with several leading international groups in systems and control, such as at Caltech and University of Stuttgart.

6. Impact and engagement in society

See IS level description in section 2.1.

2.6. The Division of Speech, Music and Hearing (TMH)

Website: https://www.kth.se/tmh/

1. Overall analysis and conclusion; strengths and development areas

a. Limited SWOT-analysis

Strengths in research

- The TMH faculty is truly multi-disciplinary including competences within computer science, speech technology, machine learning, computer animation, social robotics, linguistics, phonetics, auditory perception, and music informatics.
- TMH has a pronounced research focus in modelling perception and production of speech and music, as evidenced by its very strong publication record in the field.
- TMH is internationally well renowned in its scientific community which is evident by the large number of EU projects and organization of major conferences.
- TMH has an excellent track record in attracting external funding from many sources.
- Without exception, all TMH faculty have successfully attracted external funding, including large projects with other divisions at EECS via EU, SFF and Digital future.
- TMH has a strong record in spinoff companies and industrial collaboration.

Strengths in organization

- A flat organisational structure where the faculty are co-PIs in each other's projects applications. This makes it easier for collaboration between all PhD students.
- Own infrastructure, like seminar rooms, recording studios and motion capture lab.
- in 2019 all 11 permanent staff have faculty positions, compared to 8 out of 14 in 2012.

Weakness in research:

- Multidisciplinarity involves a risk in terms of compromising the depth of research.
- We receive undeservedly low academic citation indexes since our research publishing traditions focus less on journals than others. leading to less basic funding from KTH.

Weakness in organization

- No female faculty.

- PhD students with a variety of backgrounds can make it harder to find suitable supervisors within the division and to develop PhD level courses that fit all students.
- We are heavily dependent on external funding, thus changes in the policies of the funding agencies could make it hard to get funding for our research.
- The processes for employment, legal contracts and procurement are too slow, leading to missed opportunities (projects, recruiting the best employees, etc.)

Research profile

The research and teaching at TMH aim at an understanding of how humans communicate through speech, music, and gestures. Rooted in an engineering modelling approach, our research forms a solid base for developing multimodal human-computer interaction systems in which speech, music and gestures are used to create human-like communication. The research field is truly interdisciplinary, and is based on data collection, analysis and generation of human communicative behaviour. Central methods are obtained from speech technology, signal processing, machine learning, computer animation and robotics, and combined with knowledge from linguistics, phonetics, cognition and experimental psychology. TMH is a world renowned research department, evidenced by their participation in more than 25 EU projects and their high ratings in the KTH International Research Assessment Exercises: RAE2008 "This is an outstanding, world leading research group – among the top and most respected (a national asset)", and RAE2012 "Research output is internationally excellent in all fields, with a substantial number of units reaching the level of world-leading quality. Another sign of its international reputation is that it organized Interspeech 2017, one of the largest international speech conferences (800 papers, 2100 participants), as well as six of its satellite workshops.

a. General information of the division

Persons: Currently 27 persons: 12 faculty (12 Full professors, 3 Assoc. Prof. 2 Assistant Professors); 3 permanent researchers; 2 Postdoc; 11 PhD students. (6 more are being hired, ad period has ended, 160+ applicants)
Activities: 85% research ; 15% teaching
Funding: Stable number of externally funded projects since 2012.
Growth: The total number of employees have been stable since 2012.

b. Central research questions and themes, knowledge gaps addressed, main research activities and composition of research team(s)

Our current research areas are: Speech and Language Technologies, Human Speech and Communication, Conversational Systems, Social Robotics, Voice Science and Technical Vocology, Music Informatics and Auditory Perception. See www.kth.se/tmh for more info.

c. Contributions to the advancement of the state of the art within the research fields of the department

- Spontaneous conversational speech synthesis
- Modelling multimodal, multiparty interaction
- Modelling turn taking in interaction
- Development of spoken dialogue frameworks
- Social robotics, e.g. development of the Furhat robot
- Development of scientific clinical instrumentation for voice analysis

- Critical perspectives on the ethics of AI applied to music
- Modeling the music perception

d. Quality and quantity of contributions to the body of scientific knowledge

TMH has published a large number of high-quality publications in the period 2012-2019. Our publication strategy is to publish our work in the most prestigious Journals and conferences in our research fields. In the period we have published more than 400 papers with a journal-to-conference paper ratio of 1:2 (i.e., 156 journal articles and 277 conference and workshop papers).

Examples of high impact publications

- Alexanderson, S., O'Sullivan, C., & Beskow, J. (2016, October). Robust online motion capture labeling of finger markers. In Proceedings of the 9th International Conference on Motion in Games (pp. 7-13). (best paper award)
- Al Moubayed, S., Beskow, J., Skantze, G., & Granström, B. (2012). Furhat: a back-projected human-like robot head for multiparty human-machine interaction. In Cognitive behavioural systems (pp. 114-130). Springer.
- Al Moubayed, Samer, Jens Edlund, and Jonas Beskow. "Taming Mona Lisa: communicating gaze faithfully in 2D and 3D facial projections." *ACM Transactions on Interactive Intelligent Systems (TiiS)* 1.2 (2012): 1-25.
- Castellano, G., Pereira, A., Leite, I., Paiva, A., McOwan, P. (2009). Detecting User Engagement with a Robot Companion Using Task and Social Interaction-based Features. Proceedings of the International Conference on Multimodal Interfaces (ICMI), Cambridge, USA, 119-126. (Ten-Year Technical Impact Award at ICMI 2019)
- Elowsson, A., & Friberg, A. (2019). Modeling Music Modality with a Key-Class Invariant Pitch Chroma CNN. In 20th International Society for Music In-formation Retrieval Conference, Delft, Netherlands, 2019. (best paper award)
- Elowsson, A., & Friberg, A. (2015). Modeling the perception of tempo. J. of the Acoustical Society of America, 137(6), 3163-3177.
- Eyben, F., Scherer, K.R., Schuller, B.W., Sundberg, J., André, E., Busso, C., Devillers, L.Y., Epps, J., Laukka, P., Narayanan, S.S. and Truong, K.P., 2015. The Geneva minimalistic acoustic parameter set (GeMAPS) for voice research and affective computing. IEEE transactions on affective computing, 7(2), pp.190-202. (450 citations)
- Götze, Jana, and Boye, Johan (2016) "Learning Landmark Salience Models from Users' Route Instructions", Journal of Location Based Services,
- Henter, G. E., Lorenzo-Trueba, J., Wang, X., & Yamagishi, J. (2018). Deep encoder-decoder models for unsupervised learning of controllable speech synthesis. arXiv preprint arXiv:1807.11470.
- Johansson, M., Hori, T., Skantze, G., Höthker, A., & Gustafson, J. (2016) "Making Turn-taking Decisions for an Active Listening Robot for Memory Training", In Proc. of International Conference on Social Robotics (Best Paper Award).
- Kalpakchi, D., & Boye, J. (2019, September). SpaceRefNet: a neural approach to spatial reference resolution in a real city environment. In Proceedings of the 20th Annual SIGdial Meeting on Discourse and Dialogue (pp. 422-431) (Nominated for the Best Paper Award)
- Malisz, Z., Brandt, E., Möbius, B., Oh, Y. M., & Andreeva, B. (2018). Dimensions of segmental variability: Interaction of prosody and surprisal in six languages. Frontiers in Communication, 3, 25.
- Oertel, Catharine, Cummins, Fred, Edlund, Jens, Wagner, Petra, and Campbell, Nick (2013) "D64 : A corpus of richly recorded conversational interaction", Journal on Multimodal User Interfaces 7.1-2 (2013): 19-28.
- Pereira, A.,Catharine Oertel, C., Fermoselle, L., Mendelson, J. and Gustafson, J. (2019) "Responsive Joint Attention in Human-Robot Interaction", IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (Novel Technology Paper Award for Amusement Culture)
- Skantze, G. (2017, August). Towards a General, Continuous Model of Turn-taking in Spoken Dialogue using LSTM Recurrent Neural Networks. In *Proceedings of the 18th Annual SIGdial Meeting on Discourse and Dialogue* (pp. 220-230).
- Sturm, “A simple method to determine if a music information retrieval system is a “horse”,” IEEE Trans. Multimedia 16(6): 1636–1644, 2014. (IEEE Transactions Multimedia Prize Paper Award (2017):)
- Szekely, Eva, Mendelson, Joseph, and Gustafson, Joakim (2017) "Synthesising uncertainty : The interplay of vocal effort and hesitation disfluencies", In Proceedings of the Annual Conference of the International Speech Communication Association, INTERSPEECH 2017.

e. Engagement in national and international research collaboration within academia and its outcomes

TMH has a good mix of research funding sources. This leads to a mix of collaborations internationally, nationally and internally at KTH. TMH are applying for more industry- and challenge-driven research funding (EU, Vinnova, PTS, WASP AI, EIT Digital/Health). We have

good contacts with international universities, companies and research environments that have offered our doctoral students internships and research visits, e.g. CMU (US), Columbia University (US), Microsoft research (US), Amazon (US), Disney Research (US), ICT-UCS (US), NII (JP), Honda Robotics (JP), Toyota Robotics (JP), Google (UK), QMUL (UK), IDIAP (CH), EPFL (CH), INESC-ID (PT), UniB (DE) and TCD (IE). EU project collaborators 2012-2019 TUM (DE), ETHZ (CH), PLUS (AT), DFKI (DE), Nuance (US), IBM (US), Daimler (DE), University of Edinburgh (UK), Heriot Watt University (UK), The University of Cambridge (UK), Pompeu Fabra University (ES), ICRAM (FR), INESC-ID (PT), CIMNE (ES), CNRS (FR), FAU (DE), University of Sheffield (UK), Universite de Lille (FR), INRIA (FR), IDIAP (CH), Universität Bielefeld (DE), Athena (GR).

f. Follow up from previous evaluations

This is how we addressed the three main suggestions from RAE 2012:

- *Encourage a climate of intellectual integration of the different groups*

  Since 2012 we have increased our collaboration with RPL, that was in the same group as TMH in the RAE 2012 (13.2 Applied computer science).

  Two SSF proposals, RPL have decided to move into the same building as TMH.

- *The dependence of external funding bears the risk of discouraging long term and risky research initiatives.*

  We are engaged in ICT TNG and Digital futures. we have projects with longer project durations (five years) from SSF, ERC, Digital Future, and a speech technology infrastructure (Språkbanken Tal) seven years of funding 22 MSEK.

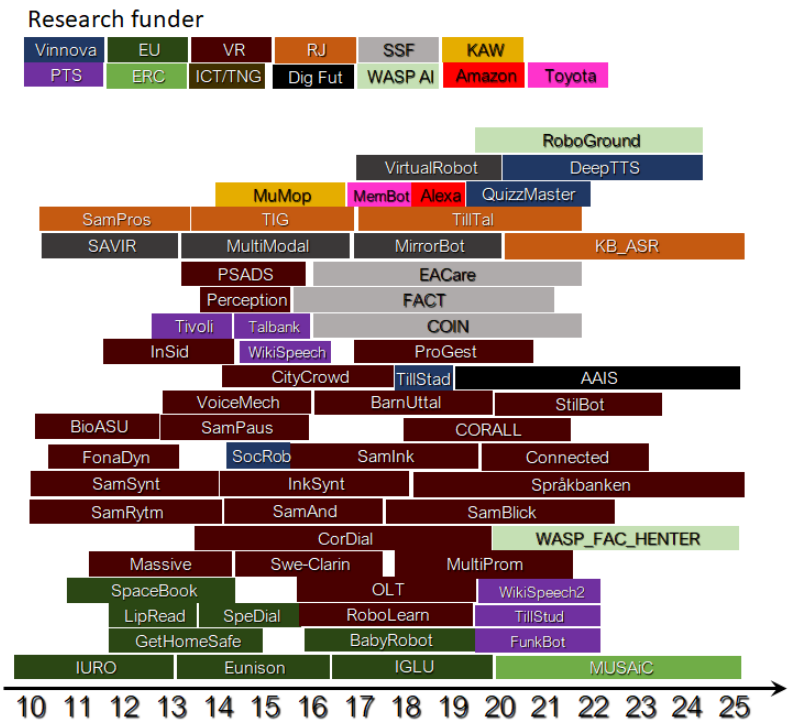
- *The process to hire new faculty takes too long time, with the risk that the best joins another university in the meantime.*

  We have employed four very good postdoc researchers that we encourage to apply to faculty positions that we and WASP announces. This means that we have a better chance at getting them to apply and then wait the long time it takes to be called for an interview. Two of them applied to the WASP AI position for an assistant professor in Intelligent Systems with specialization. in Machine Learning, and both were called for an interview and one got the position with the WASP starting package.

3. Viability

a. Funding; internal and external

The last decade TMH has had external funding for more than 60 projects from a range of sources. We have a steady number of projects funded from VR (HS and NT), while the number of projects from EU has decreased. At the same time the number of projects from national agencies like RJ, SSF and VINNOVA has increased. Other new sources of research funding includes WASP and KTH Digital Futures. The last 10 years we have project funding the following agencies: ERC (1); EU (8); VR - the Swedish Research council (26); RJ - Riksbankens jubileumsfond (4); SSF - the Swedish Foundation for Strategic Research (3); VINNOVA - Sweden's innovation agency (4); PTS - The Swedish Post and Telecom Authority (6) KAW - Knut och Alice Wallenberg (1); WASP Wallenberg Artificial Intelligence, Autonomous Systems and Software Program (2) and competitive internal KTH funding like SRA ICT TNG (4) and KTH Digital Futures (1).



b. Academic culture

Our Faculty members are highly successful and recognized researchers in their respective fields. Tangible proof of professional recognition includes:

Editorial Board membership: Journal on Multimodal User Interfaces, Multimodal Technologies and Interaction, Computer, Speech and Language, Speech Communication, International Journal of Human-Computer Studies, Phonetica, EURASIP Journal on Audio, Speech, and Music Processing, *Journal of Voice*, *Int'l J. of Research in Choir Singing, Logopedics, Phoniatrics, Vocology* Associate Editor for Vocology, *Acta Acustica united with Acustica* Associate Editor for Speech.

International Conference/workshop organization,

Co-Organizers: Interspeech (2017); IVA (2017); AVSP (2017); SIGDIAL (2015, 2019); DISS (2013, 2017); SLaTE, (2017); *Mapping Theoretical and Methodological Perspectives for Understanding Speech Interface Interactions (2019); Multimodal Corpora (2012, 2013, 2014, 2016, 2017, 2018); Real-time Conversations with Virtual Agents (2012); The Interdisciplinary Workshop on Feedback Behaviors in Dialog (2012);Symposium on Automatic Detection of Errors in Pronunciation Training (2012); Workshop on Identifying Intersections between Prosody, Gesture, and Conversation, (2018); Workshop on Multi-modal, multi-party interaction, ICMI, Istanbul (2014);Music Metacreation workshop (2019): Joint Conference on AI Music Creativity (CSMC + MuMe) (2020);Stockholm Music Acoustics Conference (2013),*

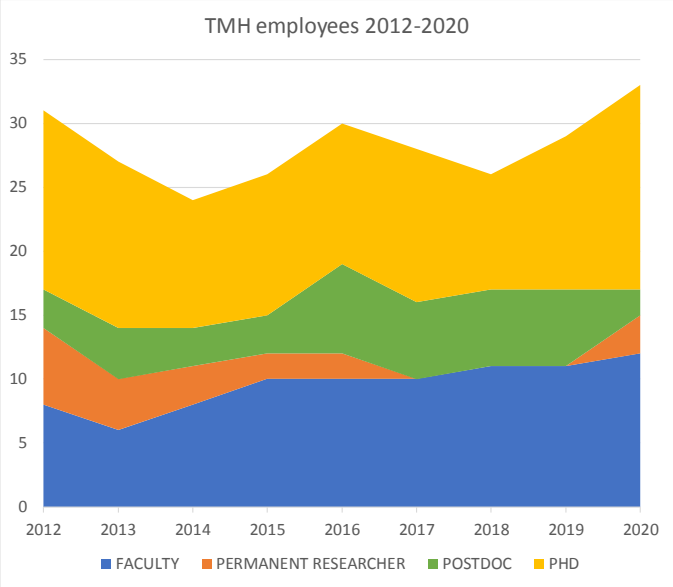
Area chairs: Interspeech (2012-2020); IVA (2017); Speech Prosody (2014); ICMI (2013, 2020); ACL 2020, ACL 2019; NAACL 2018, EACL 2017, IVA 2017.

Keynote speakers: ICPhS (2019); Nordic IoT, Helsinki, (2017); Acoustic Society of America and Acoustic Society of Japan (2016); workshop on Speech and Language Processing for Assistive Technologies (2015); Workshop on Laughter and Other Non-verbal Vocalisations (2012); Phonetics and Phonology in Europe (2015); SIGDial (2020); NeurIPS workshop on Conversational AI (2019); CLASP Workshop on Dialogue and Perception (2019); EMNLP workshop on Speech-centric NLP (2017); Workshop on Vocal Interactivity between Humans, Animals and Robots (2017); Workshop on Folk Music Analysis (2020); Voice Foundation Symposium (2017), Conference of Voice Physiology and Biomechanics, (2020) .

Invited as expert internationally: NSF Workshops (Toward User-Oriented Agents, 2019; Speech and Robots, 2019; Avatar & Robotics Signing Creatures, 2013); Dagstuhl workshops (Spoken Language Interaction with Virtual Agents and Robots, 2020: Conversational Search, 2019; Social Agents for Teamwork and Group Interactions, 2019); NII Shonan Meetings (Multimodal Agents for Ageing and Multicultural Societies,2018;The Future of Human-Robot Spoken Dialogue, 2015; Rockit Road Map for Conversational Interaction Technologies (2016), Roundtable discussions HLT, Horizon Europe (2019); Expert evaluator to the European Commission.

c. Current employment situation

TMH currently has 7 professors, 3 associate professors, 2 assistant professors and 3 permanent researchers. Since 2012 we have gone through a generation shift. Three of the professors have retired (including the head of department) and four new professors have been promoted. In 2012 we had six permanent researchers, of which five since have gotten faculty positions at KTH in international competition. Out of our current seven professors, three will retire in the coming five years. In order to prepare for future needs, and increase the probability of getting female top-level faculty we have given two of our very successful female postdocs permanent researcher positions. We currently have 11 Phd students, but an additional 6 are currently in the process of being hired in ongoing recruitments. We already have external funding for hiring another 4 PhD students through recently received ERC and VR grants.



d. Recruitment strategies

All PhD positions are announced via targeted international channels (e.g. LinkedIn, email lists like IVA, SIGDial, LINGUIST and CLARIN ERIC, as well as jobs sections on web-pages such as ISCA-web). We use our master level courses and master's degree projects to identify strong KTH students that we can contact directly. We also use our extensive international network of collaborators in academia and industry to recruit PhD students and postdocs. Our multi-disciplinarity attracts candidates from diverse educational backgrounds, mostly >50 candidates per position, allowing us to select suitable candidates. Our last two PhD positions got more than 160 applicants. We make use of our PhD students when identifying good candidates for postdoc positions. This is done is several ways, we encourage our PhD students to engage in international student activities (e.g. ISCA Student Advisory Committee) and to do internships at other universities (e.g. Columbia University or CMU). This means that they get to know PhD students that are or will look for postdoc positions. We also encourage our PhD students to suggest good late-stage PhD students (typically from Europe) that we should invite to give seminars at TMH.

e. Infrastructure and facilities

See IS level description in section 2.1.

4. Strategies and organization

a. Goals for development 5–10 years ahead

The division of Speech, Music and Hearing have a 70-year long tradition of research in speech technology and communication, where our aim has been to describe, explain and model human communicative behaviors, and to improve the technology and methodology

that allows us to do so. We also investigate how humans behave when using speech and social robotics applications, which is a multidisciplinary effort. Since we have a focus on situated, face-to-face, interaction the understanding also takes into account visual input (using motion capture, and computer vision), and the output generation includes generation of lip movements, facial gestures, communicative gestures and body postures. In general, our goal is to further develop the core speech technologies to be able to deal with conversational, naturally occurring real world speech, and to be useful in real-world situations and in real applications. Our conversational systems research aims at making interactions with these systems more fluent and/or the systems more human-like. Our goal is to further develop our incremental multimodal dialogue models, using machine learning that allows them to learn directly both from human-human conversation and from their own use in conversations with humans. Social robotics envisions a future where robots and people co-exist, collaborate and communicate on human terms, alongside each other in the same environments. The methods explored in social robotics differ sharply from traditional robot research, and focus on human interaction, collaboration, and social behaviors as applied to robots. Our goal is to explore social robotics applications in a broad range of areas, for example the intersection of the manufacturing industry and robotics, health and care and teaching/tutoring.

Analyzing and modelling the human voice apparatus brings us into contact with a wide range of disciplines, including acoustics, continuum mechanics, biomechanics, psychoacoustics, phonetics, phoniatrics, speech-language pathology, and the related signal processing. Our goal is to set up a voice research center where we harness the long-term collaboration we have with the logopedics department at KI. The center would share infrastructure, data and voice analysis methods, increasing the knowledge about human speech production and improve clinical practice.

Other well-established domains of expertise at TMH centre around music: acoustics, modeling and informatics. Historically, research in music acoustics at KTH has contributed significantly to understanding the piano, bowed instruments such as the violin, and singing voice. Research in the modeling of expression in music performance continues. Recent research in music informatics from TMH has been recognized by major awards: a best paper award at the flagship conference of music informatics (ISMIR 2019), and an ERC Consolidator Grant (ERC-2019-COG No. 864189). The latter award provides €2 million for a five year project (2020-2024) that will bring two post doctoral students and three PhD students to TMH, and further strengthen collaborations with the Royal Conservatory of Music in Stockholm. The goals of this project center around the involvement of artificial intelligence in music practices, such as listening, composing, and analysis. One goal is to facilitate the discussion of the ethics of AI in music, and the Arts in general. Another is to improve the development and application of AI to music with reference to the ethical framework developed in the project. The outcomes of this project will facilitate applications of AI to music in robust and responsible ways, impacting a wide variety of stakeholders. It will not only prepare music practitioners and audiences of the present (human and artificial) for new ways of listening, working, appraising, and developing the art form, but will also pave the way for analyzing, criticizing and broadening the AI transformation of the other Arts.

In 2022 TMH and RPL will build the Robotics and Interaction Labs (KTH IRL) on the ground floor of LV24, where we will co-locate the RPL robotics labs with the PMIL motion capture lab and the Språkbanken TAL perception lab. A joint RPL-TMH effort will be the Intelligence

Augmentation Lab, a living lab where we can explore the usefulness of augmented reality and social robots in a domestic setting. It will provide a physical setting with the advanced technical infrastructure for real-time unobtrusive capturing and processing of human motion and speech, and data presentation (sensors, displays, robots, cloud-based and local software) required for true domestic-like situation-dependent human-machine interaction. The lab will serve as an important integration and exploitation hub, where research results from different projects in social robotics and intelligent systems may be combined, matured and maintained as important showcases, for demos, education and user studies. The KTH IRL infrastructure will be important for our research and development the next 5-10 years.

Organisational goals

(1) *We have long-term funding for a scaled-up speech and language technology research*
(2) *We have started a master programme for speech and language technology at KTH*
(3) *We host a speech technology infrastructure for both industry and the public sector*
(4) *We have set up a strong speech technology forum for all kinds of stakeholders*

b. Congruence with university-level goals and the school(s) development plan(s)

see IS level description in section 2.1.

c. Leadership structure and collegial structure

TMH is managed by the head of division (Gustafson) with assistance of the vice-head (Beskow). The head of division is formally responsible for all projects, with project leaders given informal decision power to manage their projects. The division policy is currently to provide full central co-funding for all external projects, so that all faculty members can apply for external projects without worrying about co-funding. TMH has a flat organizational structure, and strives to maintain and foster collaboration and joint efforts among faculty members. We also engage the entire faculty in weekly Monday lunch meetings, and arrange annual division retreats where time is allocated for senior faculty to discuss strategic issues and plan for the future.

d. Strategies for high quality

At TMH we aim to publish our results at the most prominent venues in our fields of research. The faculty and PhD students have an ongoing discussion of where and how we should publish (e.g. publishing in arxiv or not). We have traditionally mainly published in conferences and journals in speech technology and music informatics. As our fields of research have broadened into multimodal interaction and social robotics, we have increased our number of publications in these areas. If we compare the periods 2004-2011 and 2012-2019 the number of TMH publication at ICMI has gone from 0 to 13, and the number of papers in robotic conferences (HRI, ICRA, IROS, ICSR and Ro-MAN) have increased from 5 to 18. Our ambition is to continue to do state-of-the art research on an international level in all areas we expand to.

Table. H5 index, journal/conference name (number of publications since 2012)

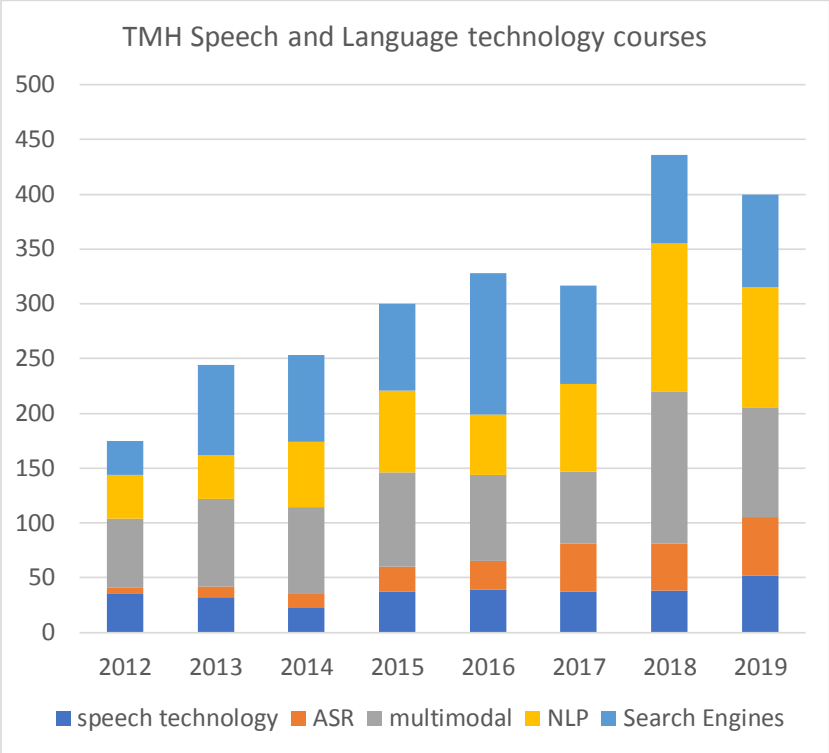
106 *PLoS ONE* (7)	33 **ICMI** - Int. Conference on Multimodal Interfaces - 12
92 *Frontiers in Psychology* (5)	32 **ISMIR** - Int. Soc. for Music Information Retrieval - 4
87 **CHI** - Computer Human Interaction (87) 1	32 *Speech Communication* - 4
82 **ICRA** - IEEE Conference on Robotics and Automation (2)	32 *Journal of Voice* - 34
80 **ICASSP** - Acoustics, Speech, and Signal Processing (5)	31 **CogSci** - Annual Meeting of Cognitive Science Society - 1
67 **IJCAI** - Int. Joint Conferences on Artificial Intelligence (1)	26 **SIGDIAL** -SIG on Discourse and Dialogue - 9
65 **Interspeech** - International Speech Communication Ass. (40)	24 **RO-MAN** - Robot & Human Interactive Communication - 1

58 **IROS** - Int. Conf. on Intelligent Robots and Systems (2)	20 *Journal on Multimodal User Interfaces* - 5
57 *The Journal of the Acoustical Society of America* (16)	19 **IVA** - ACM Conference on Intelligent Virtual Agents - 9
57 *IEEE Trans. on Cognitive and Developmental systems* (3)	17 *IEEE Trans. on Cognitive and Developmental systems* - 3
45 **LREC** - Conf. on Language Resources and Evaluation (16)	17 *Language and Speech* - 2
40 **HRI** - Conference on Human Robot Interaction (6)	15 *Journal of New Music Research* - 2
40 **AAMAS** - Autonomous Agents and Multiagent Systems (2)	14 *Logopedics Phoniatrics Vocology* - 4
38 *Applied Acoustic*s (3)	12 *Phonetica* -3
36 *Computer Speech & Language* (5)	- **Speech Prosody** (Biennial Conference on Speech Prosody (7)
36 *Journal of Speech Language and hearin*g (3)	- **ICPhS** - Quadrennial Congress of Phonetic Sciences (6)

We strive to make our publications available through open access, our source code through Github and our data, tools and corpora through Språkbanken Tal. We encourage all of our PhD students to spend 3-6 month on international internships at universities or companies. We also strive to invite the top researchers in the field of research of the PhD student as opponents in their PhD defenses. In total we have had 65 faculty opponents from 14 countries, top three are US (25), Sweden (10) and UK (8). The list of prominent researchers include James Flanagan, Ken Stevens, Manfred Schroeder, Roger Moore, Jim Glass, Gerard Bailly, Julia Hirschberg, Catherine Pelachaud, Alex Rudnicky, David Traum, Gerhard Widmer, Jim Woodhouse and Ingo Titze.

5. Interaction between research and teaching

TMH teaches 5 scheduled courses at BSc level, 8 at MSc level and 3 at PhD level. In addition we have 3 unscheduled individual courses at MSc level, and are extensively engaged in BSc and MSc degree project supervision/examination across the IS, HCT, CS and ICT departments. All courses are connected to and inspired by our core topics of research, and we are involved in several of the very large courses in machine learning. The BSc level



course DT1175 is an introductory course both to Sound in Media Technology and to the general field of Speech, Music and Hearing. It points to the later courses which attract students wishing to be initiated in our core research areas. These areas are reflected in the large number of hands-on projects in our MSc courses. Many of the degree projects are carried out in-house, which connects students to our research. Furthermore, PhD thesis students perform a significant portion of all our scientific work. Our courses in speech and language technology have followed the global trend of increasing in size the last decade, as in shown in the figure.

6. Impact and engagement in society

See IS level description in section 2.1.

3. The Department of Medical Technology and Health

3.1. Overall analysis and conclusion; strengths and development areas

a. *Limited SWOT-analysis*

Strengths:

- Agreement on three themes in the research has significantly strengthened the research focus, and different disciplines collaborate towards the outside world in education and research.
- Increased autonomy in decision making through disentangling infrastructure and groups from other stakeholders, while strengthening the role in being leading in research collaborations
- Integration between research and education in a modern facility has taken shape over the last 2 years, and the department has an important role in reaching new student groups in Southern Stockholm.
- New recruitments of high quality and potential that deliver (new professors) and strengthen the core focus (younger faculty).
- Excellent collaborative skills with external stakeholders, as well as impact. Demands for MTH research (and education) is increasing in many areas.
- Infrastructures have good quality.

Weaknesses:

- Not all faculty equally engages in research. High teaching loads, low staffing levels, and historic situations make for a large number of faculty and some researchers who teach more than 80% of their time. Simultaneously, there are faculty members with almost no teaching with varying levels of external research funding. There is a historic mismatch between the faculty composition and the educational programs, and between the faculty composition and the realistically achievable quality research environment.
- While improving, publications do not reach enough top journals. Publications have also been as wide as the composition of the department, thereby not gaining sufficient visibility both (inter)nationally and within KTH.
- Gender balance in the faculty and department as a whole has deteriorated, particularly at the senior level. Some division are better than others, with Health Informatics and Logistics, Environmental Physiology and Structural Biotechnology currently being weakest in this aspect.
- The medical sensor and signals competence has thinned out and is under reconstruction. This is a key competence area for MTH and needs urgent attention.
- The broad character of the department (while significantly reduced), still makes it challenging to provide a single academic platform for scientific exchange.
- Faculty funding is low compared to education and number of staff, thereby limiting much needed expansion. External funding is also on the low side, but at a good level for the faculty with successful project portfolios within the department.
- Lab infrastructure is focused on few disciplines, and create dependencies with other facilities. The lack of wetlab at MTH is recently solved.

Opportunities:

- The external research funding per faculty member could increase significantly. A moderate increase in time for writing good applications could yield a large number of new PhD students and postdocs.
- Building on the increased integration of education and research, the in-house capacity for projects is increasing and could provide critical mass in forthcoming years, thereby creating a base for further externally funded applications.
- Within biomedical imaging, the critical mass and infrastructure exists to grow, particularly on the pipeline between image acquisition and processing and simulation. Funding opportunities in this area are abundant.
- Health systems research has found its unique edge and rapidly gains external funding. This provides opportunities for increasing long-term quality cross-disciplinary research.
- The broader ergonomics field has increasing focus on engineering methods and technologically leading research, thereby attracting new sources of funding but also more opportunities to collaborate.
- The reorganization and the new CBH school constellation is opening the health related field within KTH for increased cooperation. Bridging the excellent research in the SciLifeLab realm with our systems approaches, imaging, and simulation capabilities fits the type of European calls drafted for Horizon Europe.

Threats:

- The number of senior faculty with a good funding track record is limited, and some of them will retire soon. Successful external research funding is therefore reliant on a fairly junior faculty base. MTH is highly vulnerable if any of the younger professors would leave, and is currently managing the generational transition for Structural Biotechnology, Biomedical Imaging, Technology in Health Care and Environmental Physiology.
- Rental costs and other fixed costs have been more than double the level of other departments at KTH. While there is some reason to hope for improvement during 2020, the structurally unfair level playing field for Flemingsberg will be the end of the motivation for the leading researchers if not urgently remedied.
- While not exactly the core of the biomedical engineering and health systems field, the bachelor programs in computer science and electronics that MTH teaches form an important stable funding for teaching and a student base, while also having many synergy effects with the biomedical engineering programs. Moving any of these programs to the EECS school would remove the base for growing the research environment.
- The fact that many other departments within KTH and the Stockholm cluster do related, and sometimes partially overlapping research makes the department vulnerable for political play with external funding from strategic investments. MTH still suffers from a bad reputation and clashes of characters from over a decade ago. The location in Flemingsberg is also negative for people with a Stockholm history. The current management works daily to mitigate this threat, but it appears regularly.

Development areas MTH:

- The first and foremost prioritized development is revitalizing the faculty composition. There is some funding available to take first steps during 2020, but this only covers the most urgent needs. The window of opportunity with a massive retirement wave is

closing, and with the pressure to keep education going, the risk is that we do not have the time or funds to transform a limited number of adjunkt (full time teaching) positions into faculty.
New positions announced over the last 2 years are strengthening existing competencies to build critical mass and mitigate retirements. A strategic investment is needed to break the vicious cycle of understaffed groups. A program for which the head of school and head of department lobbied heavily during 2019 has been funded by rector for 25% of the level requested. More is needed here.
Recruitment of new faculty is also a great opportunity to correct the gender balance, and has proven to be beneficial for the publication results too.

- The integration with hospitals, health industry and other stakeholders needs to further develop. Engaging with the Campus Flemingsberg neighbors is ongoing but needs further development. Interesting is that the distinction between research and education disappears in these settings as the focus is shifted from research grant applications to environments in which we can learn, study and research.
- A further integration of the department with the rest of KTH is quickly developing but needs further strengthening, Under the STH identity, Haninge and Flemingsberg were simply not on the radar for KTH at large, and often not in a positive way for research. The new school constellation with CBH has had a positive effect but needs to get further consequences in that groups from other campuses with synergies with MTH would move to Flemingsberg. A higher utilization by other Stockholm-based or KTH groups of the infrastructures in Solna and Flemingsberg is desirable.
- A sustained effort in internal collaboration and academic exchange should support a further reduction of the scope of MTH, without harming any of the competencies of the researchers and faculty. An example is the new assistant professor between neuronics engineering and biomedical imaging focusing on the transfer from images to simulations for head-related research. Such position strengthens both groups, while focusing the imaging research more on the head, and the neuronics engineering research more on the sources of its simulation models.

b. *Summary statement on contributions of department on impact, infrastructure and sustainable development*

- Historically, MTH has delivered a disproportionally large number of spin-offs, and a really close interaction with societal stakeholders, particularly in the medical and health domain. Impact is achieved through commercializing new products, but even more through advise and co-development with hospitals, defense force and production industry.
- The research infrastructure available in the department is of high quality, but limited to medical imaging and environmental physiology domains.
- Compared to other parts of KTH, the research at MTH has a larger focus on goals 3 and 8 and to a lesser extent 11 and others. While the department has not been particularly good in using the keywords that are measured in the internal system, it is hard to interpret the research contributions as any other than directly contributing to the SDGs.

3.2. Research profile

a. *General information of the department*

MTH is the department (institution) of biomedical engineering and health systems. It is the second largest department within the School of Engineering Sciences in Chemistry, Biotechnology and Health and evolved from the earlier School of Technology and Health.

The majority of MTH is located on Campus Flemingsberg, after moving into a new building in 2016 from Haninge and Flemingsberg. The division of Environmental Physiology is located on the campus Solna due to its research infrastructure that cannot be moved.

The department consists of 8 divisions, of which 7 are involved in research. The profile and composition of the divisions is as:

- Biomedical imaging (1 Prof, 4 Assoc. Prof, 1 Adjunkt, 2 researchers, 1 Postdocs, 6 PhD students, 2 others)
  This division works with imaging techniques used for clinical medicine or basic biomedical research. Research in data acquisition and image reconstruction includes novel ultrasound techniques, new ultrasound contrast media and construction of an experimental PET/CT scanner. The research group in image processing and visualization, led by the division head Prof. Örjan Smedby, focuses on solving medical research problems with image processing methods, currently mostly using advanced machine learning (AI) algorithms.
- Health Informatics and Logistics (1 Prof, 1 Assoc. Prof, 2 Ass. Prof, 8 Adjunkts, 1 researcher, 1 postdoc, 7 PhD students, 1 other)
  This division is a merger between the teaching unit responsible for the majority of the computer science and electrical engineering bachelors, and the research unit in health care logistics which mainly consists of a methodological group in complex system simulation and gaming. Recognizing the joint interests in software, simulation and sensor information, the groups joined in 2018, while also recruiting 2 assistant professors.
  The research is led by Prof. Sebastiaan Meijer, who has been developing his research in design of complex systems with participatory simulation and gaming methods towards the health care sector after joining STH/MTH in 2015.
- Neuronics Engineering (1 Prof, 1 Assist. Prof, 3 researchers, 6 PhD students)
  The word Neuronics comes from a combination of the medical term neurotrauma and the technical term mechanics. The objective of the research is to combine knowledge within engineering and medicine aimed at the improvement of prevention, diagnosis and treatment of injury to the human nervous system. Our vision is to reduce the number of injuries to the head and neck as a result of external violence.Our goal is to develop new and effective technology innovations for prevention and clinical treatment, primarily within neurosurgery.
- Technology in Health Care (1 Prof, 1 Assist. Prof under recruitment, 1 researcher, 4 PhD students)
  This division is working on digitization and demographic change, with regard to the shift of health care activities from hospitals to homes and mobile, from illness to increased emphasis on the individual's health and active participation in

rehabilitation and health promotion. The research provides a fundamental basis for designing technological innovations in a socially conscious manner and in developing a methodology to increase relevance in the adoption of robots and AI-controlled applications and the sustainability of digital systems. Important questions are the expectations and needs of growing older generations and the innovative value of their life experiences. The subject Technology in Health Care, implemented in 2014, is multidisciplinary, based on social science and technology studies including design methodology, ethnology, sociology and nursing. Recognizing the growing demand for this knowledge an assistant professor is under recruitment. The research is led by Prof. Britt Östlund, employed at KTH 2014, whom in the last thirty years has been dedicated to research and development in aging, technology and design, previously at Lund University.

- Environmental Physiology (1 Prof, 1 Assist. Prof, 4 researchers, 2 Postdocs, 4 PhD students, 2 others)
  This division works on the influence of environmental factors on physiological responses in humans. The subject comprises four research fields: high-altitude physiology, thermal physiology, gravitational physiology and diving physiology and is predominantly based on experimental research. Research questions may vary from basic science-related to applied, of which the latter commonly concerns the interdisciplinary area of physiology and technology, for instance development of protective equipment and strategies that will enable humans to tolerate extreme environments. The division is located in Solna, where it possesses special facilities in terms of a human-use centrifuge and hyper- and hypobaric pressure chambers. The division of Environmental Physiology is predominantly financed by external research grants, from the Swedish Armed Forces, the European and Swedish Space Agencies and others. The research is since many years led by Prof. Ola Eiken.
- Ergonomics (2 Prof, 1 Prof Emeritus, 1. Prof affiliated, 2 Assoc. Prof, 2 Adjunkts, 2 researchers, 10 PhD students, 1 other)
  This division works with the development of theories, methods and design strategies in order to improve the physical and psychosocial work conditions. The research includes design and interplay between technology, organization, and human capabilities, in order to optimize health and operational efficiency in industrial and healthcare systems. Risk assessment methods with high usability and reliability is one focus, utilizing new smart technology. A master program and several courses about sustainable, attractive and productive workplaces and products mirrors the research area of the division. The division is, since 2018, led by Prof. Mikael Forsman, who has carried out experimental and field studies, and developed technical methods in the field of ergonomics.
- Structural Biotechnology (2 Assoc. Prof, 2 researchers, 1 Postdoc, 3 PhD students)
  We center our research around application of cryo transmission electron microscopy in biology. We have close ties to medical imaging due to our use of image analysis and biology and biochemistry due to the type of specimens we study. The department consists of 4 main research areas: The role of proteins in brain function. Chaperones in health and disease. Inflammatory proteins in the leukotriene and prostaglandin biosynthetic pathways. Improving cryo electron microscopy for biological specimens.
- Basic Science Education (3 Assoc. prof, 11 adjunkts)

This division is teaching exclusively and provides the courses for the preparatory year / semester and the base courses in the bachelor programs. The three faculty persons are not doing research (within their KTH hours).

The department also has 2 centers:

- Jonassons center for medical imaging
  The Jonasson Center for Medical Imaging is an infrastructure center based on a large donation (by Kerstin and Rune Jonasson) in 2011. The center provides researchers at KTH, Karolinska Institute and Karolinska Hospital with access to equipment for experimental, clinical or preclinical imaging, including radiography, ultrasound, photoacoustic imaging, magnetic resonance imaging, nuclear medicine imaging, advanced light microscopy and electron microscopy. In addition, there is a virtual reality theatre with stereoscopic projection and a server for computationally demanding AI experiments.
- Swedish Aerospace Physiology Centre (SAPC) is located in Solna, where it shares research facilities and personnel with the div. of Environmental Physiology. The overall aims of the SAPC are to conduct and support research, development and teaching that may act to improve medical safety in aviation and during manned space flights. SAPC research predominantly concerns different aspects of physiology but also development of technology. The research projects are commonly conducted as national or international collaborations. For instance, SAPC has, during the last 6 years, been involved in multinational studies concerning the effects of musculoskeletal and cardiovascular unloading in combination with hypoxia, conditions that are anticipated in future manned habitats on the Moon and Mars. SAPC is part of the "umbrella organization" KTH Space Center.

b. *Central research questions and themes, knowledge gaps addressed, main research activities and composition of research team(s)*

The department concentrates on three themes in the research. These themes have been established in 2018 after the reorganization, after a faculty process during 2017.

Below we discuss per theme the topics, and specific knowledge gaps, as well as other relevant aspects.

Theme 1: Biomedical imaging and simulation
Three divisions contribute mainly to this theme: being Biomedical Imaging, Neuronics Engineering and Structural Biotechnology. Also, the Jonassons center for biomedical imaging is an important ingredient.
The research focusses particularly on processing of biomedical images (including AI), improvement of medical models from image capture data, the construction and validation of biomechanical models (with a focus on the head and heart regions), and the study of biological structures and their functions both at a molecular and a cellular level. The department has limited research in actual image capture, but owns a large range of imaging modalities.

A relatively large part of the faculty works in imaging. It is of later years that more

collaboration around this theme is occuring, with the goal of establishing better pipelines from image acquisition to validated models, where multidisciplinary collaboration is of key importance.

Gender is a known issue in the research in this theme due to the data bias in reference data sets. The department actively tries to address this in the formulation of research projects, and has some more recent efforts in maternity care around birth-giving.

Theme 2: Sustainable work life

This is the core topic of 2 divisions: Ergonomics and Environmental Physiology. Furthermore, there are contributions from Technology in Health Care and Health Informatics and Logistics.

The main research questions focus on how to keep workers safe under repeated stress, with the bulk of the research involving physically stressing factors. The availability of sensors to objectify strain is a growing research topic, and here there are multidisciplinary collaborations with health informatics and with technology in health care to provide IoT, organisational and sociological perspectives. Special competence exists in work under extreme circumstances, be it altitude or depth, cold or G-forces.

Gender and other diversity aspects are a natural part of this research

Theme 3: Digitalisation in Health and Care

This emerging theme is predominantly the research domain of Health Informatics and Logistics, and Technology in Health Care. The former is particularly doing research on how to model, simulate and game large scale, distributed systems in health care. Furthermore, the question is on how to integrate IoT sensors for health in preventative and chronic health settings, with an interest in the development of home care.

Technology in Health Care adds a sociological perspective to digitalization. What does it mean to age, what is the role of technology and how to organize meaningful care?

Contributions to the theme come from the medical imaging in the form of better decision support from images to health care professionals, and from ergonomics in the knowledge on how to interpret strain signals.

This theme is under development, and gender questions are very important though the current research has not taken this up significantly yet.

c. *Contributions to the advancement of the state of the art within the research fields of the department*

Within theme 'Biomedical Imaging and Simulation', we have the following highlights:

- New segmentation method, developed by Chunliang Wang, that enables exact volume measurements in 3D medical images with a speed that is acceptable for clinical work. This may lay a foundation for new tools for diagnosis and monitoring of diseases such as cancer, dementia or cardiovascular disorders.
- For estimation of the intravascular pressure in large arteries such as the aorta, where previously only invasive measurements were possible, David Marlevi has developed a method using phase contrast magnetic resonance imaging, virtual work-energy equations, and a virtual field, which gives estimates of the relative flow. This may in

the future have great clinical impact.

- The Neuronic engineering division has been pioneers in computational modelling of the human head and brain where methodologies of creating detailed brain injury prediction models directly from medical images have been developed and used the last ten years. These models have been the first to be successfully validated against experimental localized brain motion, and lately also experimental brain strain. In applications of the models, it has been emphasized that angular motion has to be mitigated better in design of protective devices such as helmets. One practical implication is a coming change in European bicycle testing standards which will include the addition of testing against oblique, angled impacts together with measurements of angular head kinematics. Researchers from Neuronic engineering are the convenors of this working group within CEN.
- We have developed the theory of a novel phase plate for imaging low contrast, beam sensitive specimens such as proteins in solution and cellular structures.

Within theme 'Sustainable Work Life', we have the following highlights:

- RAMP, which has been developed in collaboration with two large Swedish companies, is a risk management tool for manual handling. It is a digital assessment tool for physical ergonomics designated to assess work and provide a structure to find and take appropriate actions when needed; Three MOOCs were developed, and RAMP has now been downloaded in 89 countries. This is important to increase use of systematic methods in identifying /managing work environment risks.
- Lean Production is a strategy that is introduced in the majority of Swedish industrial companies. It has now started to be implemented hospitals and departments affect hospital staff. With expert area in management, work health and over-all in health-care systems, the division of ergonomics have successfully studied how work conditions, health, commitment and performance change in the short and long term, and how consequences for employees depend how Lean is being implemented. Rationalization is now in focus in the health-care sector. Previously most rationalizations have resulted in worsened work conditions, this research is important to change that trend.
- Together with Jozef Stefan Institute, the Environmental Physiology div./SAPC developed an experimental model and initiated a line of research to investigate the combined effects of hypoxia and inacitivity/physical unloading on numerous physiological functions. The research resulted in multinational collaborations and generated about 40 publications for the MTH. The research was initially driven by a concern for the medical consequences of conditions envisaged in future human habitats on the Moon and Mars, but has considerable impact on our understanding of the development of comorbidities associated with the combination of hypoxia and severe inactivity encountered by the growing population of individuals suffering from chronic obstructive pulmonary disease. The div. of Environmental Physiology has also developed an experimental technique allowing in vivo determinations of the mechanical properties (viz. stiffness/distensibility) of human blood vessels. The technique has been used to clarify how human blood vessels adapt to prolonged pressure unloading encountered by astronauts as well to repeated pressure loading encountered by pilots of high-performance aircraft. In addition, the finding that

repeated exposures to high intravascular pressure increases the stiffness of precapillary blood vessels reveals an important mechanism in the pathogenesis of primary hypertension in humans.

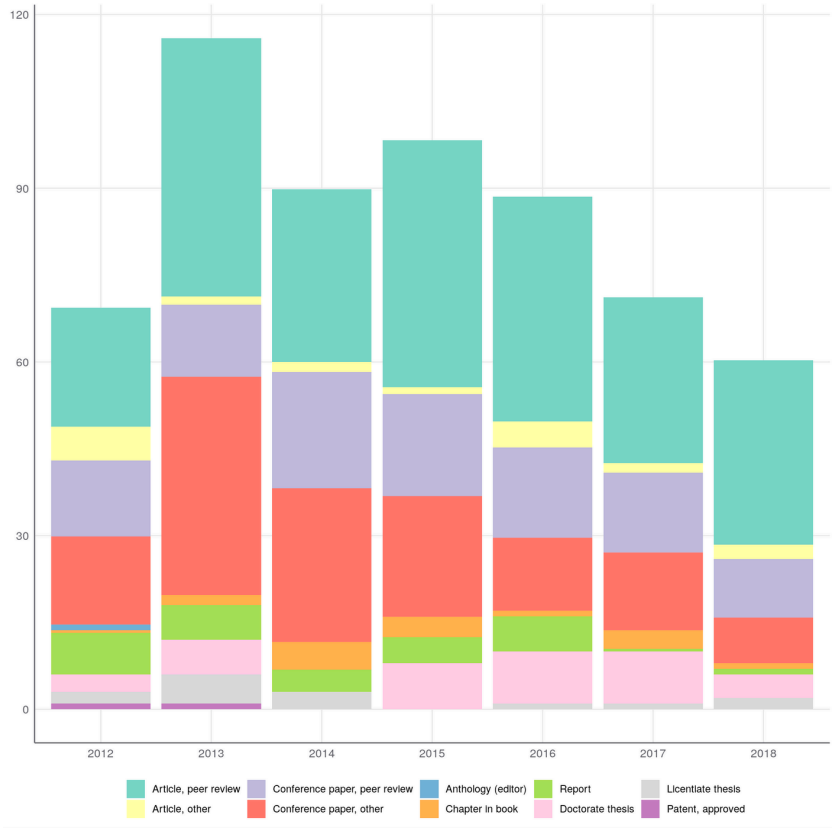
Within theme 'Digitalisation of Health and Care', we have the following highlights:

- Technology in Health Care collaborates in the KTH project: Advanced Adaptive Intelligent Systems which is an example of Human-centered Artificial Intelligence (HAI) or Intelligence Augmentation (IA). In this project the division precede the interpretation of what can be automated in the social context of older people. The aim of the project is to develop adaptive social robots that can understand humans' communicative behavior and task-related physical actions, and adapt their interaction to suit. The division laid the groundwork for engineering, for fluid and seamless adaptation of intelligent systems to users' context, needs or preferences.
- The division of Health Informatics and Logistics has developed a hybrid method for mixed-evidence large-scale system models, extending the System Dynamics and Participatory Model Building methods. This has been successfully applied in system models for Mental Health, amongst others. The division also developed multiple simulations and games to explore management of Emergency Care Logistics in a regional health care system perspective.
- The HIL division also developed the world's first Managed IoT platform for medical and health applications, and contributed multiple technologies (communication technology, coding systems) to overcome the specific issues of advanced health sensors in home care settings.

d. *Quality and quantity of contributions to the body of scientific knowledge*

The bibliometrical performance of MTH shows rather clearly what has happened between the RAE2012 and RAE2020. Firstly, the number of publications shot up in 2013 – 2015. This was during a period in which a large number of researchers have been made redundant, and they started publishing larger numbers of mainly conference papers.

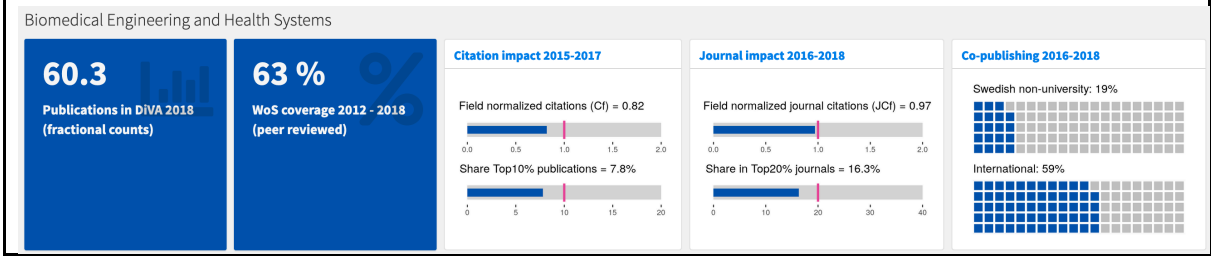
Over the years, the number of employees on the research side has decreased, and with the recruitment of 3 new professors 2013-2014, the percentage of journal publications, as well as field normalized citation rate and percentage in the top-10% outlets improved.



These numbers are pointing up, but are not good enough yet.

However, it is also important to put some context here:

- The percentage of co-publishing with international colleagues is relatively high, as is the collaboration with non-academic Swedish partners. Therefore, the fractional counts affect scores negatively, while doing the right thing.
- Particularly our health systems research is experimenting in areas where citation cultures are different, and where clearly established scientific communities are lacking. This means that the Web of Science coverage can be relatively low, and that it takes time to get recognition. Here we see very promising indications now, and publishing in good outlets is getting easier.
- We observe a need to publish in the computer science realm and to mature approaches, before getting to theory-development that can be published towards more prestigious journals.
- With a fractional journal article production of 31,8 on 17 faculty members who engaged in research in 2018, in a department with a massive teaching load is rather productive.



Biomedical Engineering and Health Systems

Publication volume, fractionalized

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DiVA publication type	2012	2013	2014	2015	2016	2017	2018	Total	WoS coverage
Article, peer review	20.5	44.6	29.9	42.7	38.8	28.6	31.8	236.9	72.5%
Article, other	5.9	1.4	1.7	1.2	4.5	1.6	2.5	18.7	81.9%
Conference paper, peer review	13.1	12.4	20.1	17.6	15.6	13.8	10.1	102.8	41.0%
Conference paper, other	15.2	37.7	26.5	20.8	12.6	13.4	7.9	134.1	0.1%
Anthology (editor)	1.0							1.0	0.0%
Chapter in book	0.5	1.8	4.8	3.5	1.0	3.2	1.0	15.8	16.9%
Report	7.2	6.0	3.8	4.5	6.0	0.5	1.0	29.1	0.0%
Doctorate thesis	3.0	6.0		8.0	9.0	9.0	4.0	39.0	0.0%
Licentiate thesis	2.0	5.0	3.0		1.0	1.0	2.0	14.0	0.0%
Patent, approved	1.0	1.0						2.0	0.0%

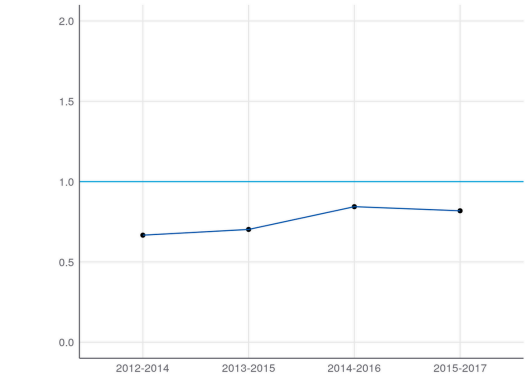
Notes

This table is based on Web of Science publication types Article, Proceedings paper, Review, Letter and Editorial.
Rows are based on at least **50** (full counted) publications with **poor** Web of Science coverage (at worst **43.8%**).
(DiVA publication types Article, peer review and Conference paper, peer review)

Notes

This table is based on Web of Science publication types Article and Review.
Rows are based on at least **144** (full counted) publications with **moderate** Web of Science coverage (at worst **68.1%**).
(DiVA publication type Article, peer review)

Average field normalized citations (Cf)



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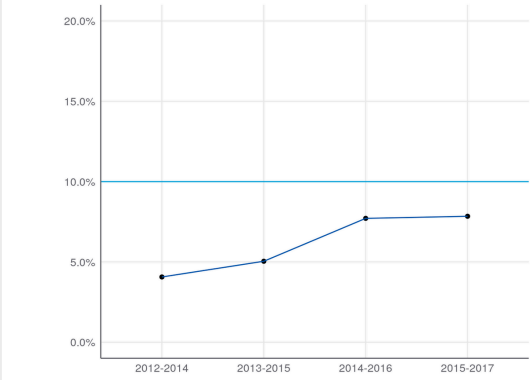

For a broad department, it is difficult to highlight just a few publications, but here we highlight one or two recent publications from each division.

Lind CM, Forsman M, Rose LM. Development and evaluation of RAMP II – a practitioner's tool for assessing musculoskeletal disorder risk factors in industrial manual handling. Ergonomics. 2020 Jan 10:1-28. doi:10.1080/00140139.2019.1710576.

Yang L, Grooten WJA, Forsman M. An iPhone application for upper arm posture and movement measurements. Appl Ergon. 2017 Nov;65:492-500. doi:10.1016/j.apergo.2017.02.012.

Fischer, B., Peine, A. & Östlund, B. (2019) The importance of user involvement: A systematic review of involving older users in technology design" The Gerontologist Doi:10.1093/geront/gnz16

Brusini I, Carneiro M, Wang CL, Rubin CJ, Ring H, Afonso S, Blanco-Aguiar JA,Ferrand N, Rafati N, Villafuerte R, Smedby Ö, Damberg P, Hallböök F, Fredrikson M, Andersson L. Changes in brain architecture are consistent with altered fear processing in domestic rabbits. Proc Natl Acad Sci U.S.A. 2018;115(28):7380-7385.

Marlevi D, Ruijsink B, Balmus M, Dillon-Murphy D, Fovargue D, Pushparajah K, et al. Estimation of Cardiovascular Relative Pressure Using Virtual Work-Energy. Scientific Reports 2019;9(1).

Montanino, A., Saeedimasine, M., Villa, A., & Kleiven, S. (2020). Localized axolemma deformations suggest mechanoporation as axonal injury trigger. Frontiers in Neurology , 11, 25:

G. Kim *et al.*, "Aldehyde-alcohol dehydrogenase forms a high-order spirosome architecture critical for its activity," *Nature Communications*, vol. 10, no. 1, 2019

P. J. B. Koeck, "Design of a Charged Particle Beam Phase Plate for Transmission Electron Microscopy," *Ultramicroscopy*, vol. 205, pp. 62-69, 2019.

Ånell R, Grönkvist M, Gennser M, Eiken O. Evolution and preservation of venous gas emboli at alternating high and moderate altitude exposures. Aerosp Med Hum Perf. 91:11-17. 2020

Zhang, C., Härenstam, K. P., Meijer, S. & Darwich, A. S. (2020). Serious Gaming of Logistics Management in Pediatric Emergency Medicine. *International Journal of Serious Games, 7*(1), 47-77.

Moustaid, E., M. Kornevs, F. Lindencrona, S. Meijer (2020). A System of Systems of Mental Health in Cities, Digging Deep into the Origins of Complexity. Administration and Policy in Mental Health and Mental Health Services Research, (), 1-11. DOI

10.1007/s10488-020-01035-0

e. *Engagement in national and international research collaboration within academia and its outcomes*

The number of collaborations is large and diverse, clearly reflecting the diversity of backgrounds and historical spread of the department. Here we list some research constellations that have proven meaningful.

Within Ergonomics: Smart workwear national research enxhange with: Scania CV AB, Volvo Lastvagnar AB, Volvo Personvagnar AB, Högskolan i Borås, Högskolan i Skövde, Högskolan i Gävle, Karolinska Institutet, Stiftelsen Fraunhofer-Chalmers Centre, Swerea IVF, Feelgood Svenska AB and Avonova Hälsa AB. Ergonomics internationally: PEROSH – Partnership for European research in occupational safety and health. Sweden is now again a member, and Prof. Mikael Forsman represents Sweden in a PEROSH-project.

Assessing and improving the static workload of surgeons: Projects together with KI, Mayo Clinic, Minnesota, and Cambridge University Hospitals. Three articles have recently been co-authored; visiting research periods.

For Biomedical Imaging there is active exchange and co-publishing with: David Nordsletten, Div. Imaging Sc. and Biomed. Eng., King's College London, UK; Alejandro Frangi, Centre for Comp. Imaging & Simulation Techn. in Biomedicine, School of Computing and School of Medicine, University of Leeds, UK; Matthew Urban, Mayo Clin, Coll Med, Dept. Radiol, Rochester, MN, USA; Xiaojun Chen, School of Biomed Eng., Shanghai, Shanghai Jiao Tong Univ, China; Punam Saha, Institute for Biomedical Imaging, Univ. of Iowa, Iowa City, IA, USA; Maxime Descoteaux, Computer Science, Université de Sherbrooke, Sherbrooke, Canada; Dieter Pahr, Institute of Lightweight Design and Structural Biomechanics, TU Wien, Vienna, Austria; Leif Andersson, Dept

Med Biochem & Microbiol, Sci Life Lab, Uppsala Univ.; Anders Persson et al. Center for Medical Image Science and Visualization (CMIV), Linköping Univ.; Eric Westman et al., Div Clinical Geriatrics, Dept Neurobiol Care Sci & Soc, Karolinska Institute; Iuliana Toma-Daşu, Dept Oncol Pathol, Karolinska Institute

For Neuronics Engineering: Karolinska Institute, Prof. Alessandra Villa (now at PDC/KTH): 4 collab. studies published involving multiscale computational modelling of axonal injuries from external kinematics to atoms. Continue with Prof. Jan Johansson at KI to focus on biologic drugs which might stabilize axonal membranes. Kath. Uni. Leuven: Prediction of acute subdural hematoma which constitute more than 50% of all severe brain injuries. Also on reconstructing some of their most well defined bicycle accidents. So far around five co-authored publications while their data have been used in around ten additional articles the last ten years. Stanford university: Prof. David Camarillo used the KTH head model for his research into concussions in Am. Football since 2013 (five co-authored publications so far and around ten additional publications by the Stanford group using the head model).

Technology in Health Care has most collaborations within the HCI, Social robotics and Sociogerontechnology communities. International collaboration within Horizon2020 on interactive robots (a.o. Utrecht Univ.) and comparative international studies on fundamental changes in the contemporary experience of later life, the intersection of digital infrastructures, place and the experience of being connected. The division contributed to creating the growing network of "Sociogerontechnology" and in 2019 organized a workshop at KTH. Consequently, the division succeeded to publish a paper in "The Gerontologist" which is counted as having the highest impact in the gerontology field. At KTH, the division collaborates with the EECS school, the robotics department in one project funded by KTH Digital Futures and at INDEK in a project on digitization of home care. In Sweden the division is part of the National Graduate School on Ageing and Health, providing technology aspects in the context of nursing and paramedical research. It should also be mentioned that the division is well established in relevant networks at several universities such as Örebro, Umeå, Lund and Malmö.

Structural biotechnology works nationally with: Gunnar Hansson at the Uni. Göteborg in the field of mucins and respiratory disorders leading to 4 publications in leading journals. Jan Johansson at Karolinska Institute on BRICHOS molecules as chaperones in prevention of Alzheimer's disease: so far led to 1 paper in Nature Communications. Jens Lagerstedt at Lund University regarding structure and function of high density lipoprotein, also denoted the "good cholesterol". 1 paper published in Sci. Rep. Within KTH (Jonas Weissenrieder and Joydeep Dutta) to develop a prototype of our proposed phase-plate published in Ultramicroscopy.

International: Ji-Joon Song at KAIST/Korea in the field of Huntington disease has so far led to 4 high impact publications. Larry Marnett, Vanderbilt University, Bruce Hammock, UCSD and Ralf Morgenstern, KI, regarding the structural interaction of two proteins in the inflammatory pathway, COX-2 and MPGES1, stabilised in nanodiscs.

The div of Environmental Physiology regularly conduct research projects in collaboration with international and national academic partners. Examples of international partners: Jozef Stefan Institute, Ljubljana, Slovenia; University of Udine, Italy; University Hospital, LMU Munich, Germany; Institute of Aerospace Medicine, German Aerospace Center, Cologne, Germany; University of Nottingham Medical School,

Nottingham, UK. National partners are for example: Karolinska Institute, Stockholm; Högskolan i Gävle; Göteborgs Universitet

Health Informatics and Logistics works with several partners in EU projects, amongst others TU Delft, KU Leuven, Politecnico di Milano, Politecnico di Turino, IBM research Dublin, Danska Teknologiska Institutet, Danska Tekniska Universitet. We are part of a Health System Engineering workgroup with Cambridge, DTU and TU Delft, a.o. Within Sweden, we work mostly with GiH and Karolinska Institutet.

f. *Follow up from previous evaluations*

MTH has seen a very challenging period following the RAE 2012.

Within UoA 4.2 (Biomedical Engineering), the score on research output was average (3), but impact high (5) and research environment above average (4). The main recommendations were:

- *Develop a long term strategy.*
- *Intermediate age high quality faculty appointments are needed --- with an attention to research output quality and including a focus on gender balance.*
- *Strengthen the link between basic engineering, including other groups from KTH, and the clinical environment. Strengthen the interaction between engineers and medical doctors in the clinical environment by providing space for engineers in the hospital.*
- *Don't diversify the research too much but keep it focused to a few priority areas, in which the UoA can build up a research group above critical size, attract the top research leaders in these fields and excel. Successful examples from the past have been in head injury analysis and crash helmet development and cardiovascular ultrasound imaging.*

Within UoA 8.3 (Ergonomics, Health & Building), the scores for output was average (3), impact average (3) and research environment poor (2), with particular remarks on the DASH and Lighting units. The main recommendations were:

1) That the core staff mentioned above establish a dedicated effort to realise the research potential within the UoA. We suggest that in the first instance this effort is co-ordinated by Eklund as he has recent experience of developing a successful, new area of research activity.

2) That the importance of human factors and ergonomics specialists within the School of Industrial and Technology Management is evident. Other units of assessment within KTH would benefit of staff with the same type of specialisation. In addition, attention should be given to assure coordination between relevant groups within 8.1 and 8.4 that require human factors / ergonomics input. These include, amongst many, for example, the digital factory, working life and haptic devices.

3) DASH should be asked to prepare a detailed research strategy and identify a programme of research to realise this.

4) The DASH division is encouraged to enforce cooperation with UoAs 8.1 and 8.2 to make better use of modeling and design methodologies and design tools being state of the art in technical product design for application in patient care systems design. These state of the art rigorous engineering approaches may bring a big step forward to the currently mainly qualitative design principles used in the DASH context.

5) to enable this unit to achieve a sustained, international profile we suggest they explore the notion of twinning with an international peer group to which they aspire. Such a twinning exercise would encourage activities that are both excellent and truly internationally relevant.

MTH predecessor STH has landed in major economic issues 2012-2014. The economic viability of well-scoring groups in biomedical engineering was low due to a significant number of senior researchers who did not bring in significant funding. Even worse was the economic situation around UoA 8.2, where on one hand the DASH and lighting groups were unfunded, and later the newly built Patient Safety group with high-profile recruit Prof Richard Cook (2011) had to be dismantled due to poor recruitment. Even other groups within the school suffered from similar issues. In summary, one can say that the aggressive expansion 2009 – 2012 has not been backed up by long-term strategy.

In 2013, groups that covered lighting and building management moved to the ABE school. During 2014, the then-new STH dean started an economic reorganisation, during which about 15 people were forced to leave and another 5 chose to leave. This has caused massive unrest, social and financial costs and led to pigeon-holing of all groups. DASH was slowly dismantled.

Meanwhile, 3 professor positions have been filled in new areas (Medical Image Processing (Örjan Smedby, 2014), Technology in Health Care (Britt Östlund, 2014) and Health Care Logistics (Sebastiaan Meijer, 2015). Smedby brought new excellence in an established domain, where Östlund and Meijer are building new research areas and delivering.

In 2016, the locations in Haninge and Flemingsberg moved into a brand-new building 'Technology for Health' in front of the main entrance to the Karolinska Huddinge hospital. Since then, the collaboration between teaching and research has improved.

It is a mystery as to why the RAE2012 recommendations have not been implemented earlier. It is paramount that STH was too fragmented, without critical mass, and lacked research quality in certain pockets. The department is happy that the developments of the last couple of years finally go in the right direction. There are three mechanisms that we want to highlight:

- Newly started groups and professors have taken time to get integrated. They were positioned as research-only units, where it is essential to be integrated in education and the management of the department as well. For years, a clustering existed in which professors were positioned to lead only their own research group, where management was done by competent but not research-heavy persons. The changes since the reorganization 2018 have made the structure more traditionally academic, as this is needed to increase research quality.
- Meanwhile, good research groups have been highly frustrated about the lack of prioritization of new faculty positions and investments to build critical mass. Apart from the new professors, the investments clearly followed the interests of the top management.
- Good infrastructure, like the Cryo-EM facilty, received financial protection because of the enormous potential. The fantastic Jonasson donation to start the Jonassons center for medical imaging has enabled the acquisition of very expensive infrastructure. At the same time, the management to capitalize on these infrastructures has only been

partially successful. Some of the Jonasson infrastructure has led to very good KTH publications, but others have not been used by KTH and more KI. The structural biotechnology group has consistently delivered high quality publications, but also suffered massive financial losses.

3.3 Viability

a. *Funding; internal and external*

The finances of the department are grossly characterized as: 40% Education (GRU), 30% Base funding research (FOFU), 30% External research funding

The external research funding has increased after 2012, particularly around the 3 new professorships, but has stagnated a bit the last couple of years. This can be explained by a larger decrease in the number of total persons involved in research, as well as several larger EU projects ending simultaneously. The funding per faculty member in research went up, which we see as a start of a positive movement. In 2019/2020, several groups are applying for larger grants, and we see already some results, with the expectations that the total amount of external funding can fairly easily grow with some 30%

The largest sources of financing are:

- Swedish defense – with a long-term funding and intention to increase for the Environmental Physiology division.
- VINNOVA – the Swedish innovation funding agency (and to a certain extent FORTE and FORMAS), showing the close-to-implementation research ongoing
- The donation of Rune and Kerstin Jonasson – funding the Jonassons center. In 2020, we received a last additional donation of 11 mSEK.
- EU projects, from FP7/H2020, EIT (Health), and Marie Curie.
- Region Stockholm (earlier SLL) – with startup funding for 2 professorships, and now an increasing number of projects directly funded from them.

Furthermore, there is a portfolio of projects from the Swedish Science Foundation (VR), some international platforms like EUROSTARS and the NIH, as well as industrial projects with for instance Scania. The funding of MTH is relatively diverse, and could use some increase on the purely scientific funding. Initiatives together with other CBH and KTH departments are ongoing.

b. *Academic culture*

MTH has for a long time been split into a research and a teaching community, with the exception of the biomedical imaging and ergonomics units. Since the move into one building, and the subsequent organizational changes, more of an integrated academic community is being shaped. It has proven not yet possible to create a unified lecture series for the diverse department, but progress has been made in the faculty group, institutionsforum, and smaller seminar series like around the Jonassons center, Ergonomics and Technology in Health Care.

c. *Current faculty situation*

Currently, the faculty is composed of 7 professors, 15 associate professors, 4 assistant

professors, and 18 adjunkts (full time teachers), with about 30% females. There are 6 recruitments ongoing at the time of writing, mainly at the assistant professor level and few adjunkts.

The MTH faculty is undergoing a massive generational shift. The last years, already 7 faculty and adjunkts retired, and another 13 persons (4 professors, 5 associate professors, 4 adjunkts) are expected to retire in the next 4 years. The aim is to correct some earlier imbalances by recruiting more faculty to strong groups who have been neglected, as well as to fill the gaps in our educational needs, which have synergies with the research areas. Education for which we need to recruit but that does not have synergy with the research is actively outsourced to other parts of KTH (Example: power electronics).

d. *Recruitment strategies*

The recruitment strategies have been brought in line with the overall KTH strategies, which has led to a higher quality and higher numbers of applicants. The results of actual recruitments show that equal opportunities are relatively well safeguarded. The groups with a skewed gender balance have particularly not been able to recruit new senior personnel recently.

e. *Infrastructure and facilities*

We have 1 cryo transmission electron microscope with a modern CMOS detector and a direct electron detector and all the equipment necessary for protein specimen preparation. The direct detector has to be replaced or renovated at a cost of 0.5 to 1.5 million SEK in order to maintain high-quality imaging capabilities.

Currently a wet lab at the premises in Campus Flemingsberg is established. Rights to carry out GMM-f based work has been obtained. We aim at being self-sufficient regarding protein production as well as sample quality assessment. For this purpose we would need a gel filtration system in the near future. For thorough research with publication in high impact journals methodology provided by National facilities and by collaborations will be mined however acquisition of methodology or infrastructure for biochemical/biophysical characterisation may have to be considered.

The Solna Campus holds special research facilities, in terms of centrifuge and hyper- and hypobaric pressure chambers as well as a climatic chamber, all designed for experiments in humans. The performance standards for these facilities are:

• centrifuge; radius = 7.25 m, max. G load = 15 G, peak G onset rate = 5 G/sec)

• hypobaric chamber; volume = 23 m^3, min. pressure = 3 kPa)

• hyperbaric chamber 1; volume = 10 m^3, max. pressure = 15 ATM)

• hyperbaric chamber 2; volume = 5 m^3, max. pressure = 5 ATM.

• climatic chamber; volume = 18 m^3, operating temp.-range -20 to + 50 °C.

Although old, these facilities have been upgraded and currently have acceptable-good performance standards in an international perspective. The facilities need continuous maintenance.

In the Jonassons center, imaging infrastructure is available in:

Photoacoustic Imaging Facility

The photoacoustic imaging system (Vevo LAZR, Visualsonics) incorporates

photoacoustic imaging into high-resolution ultrasound. The ultrasound imaging provides a high-resolution reference map for identifying anatomy, while the photoacoustic imaging enables functional measurements such as oxygen saturation, total hemoglobin and the microdistribution of biomarkers. This infrastructure is located at KI and needs upgrading. It is under reconsideration.

Vivid E9 Ultrasound system from GE Healthcare is a first of its kind cardiovascular ultrasound system exclusively built for 4D imaging. Vivid E9 is an exceptional tool for image acquisition, data management and archiving that helps to enhance productivity and increase confidence in diagnostics.

Aixplorer Ultrasound System is an ultrasound system that, in addition to conventional ultrasound imaging, can also perform elastography imaging. With elastography imaging the clinician can know how hard or soft the tissue is and does not have to rely only on manual palpation.

Verasonics V-1 Ultrasound System which can be programmed to perform many cutting-edge ultrasound techniques in research settings.

Mobile Gamma camera This is a powerful, fast, bed-side diagnostic equipment for cardiology or neurology applications.

MTH microCT – miniPET A combined CT and PET with superior spatial resolution for small animal imaging. The system has been developed by the Medical Imaging group at MTH in collaboration with ATOMKI, Debrecen (Hungary) and it is therefore fully customizable to any needs of interest.

Mobile C-arm. Ziehm Vision RFD. This has a flat-panel detector that provides high resolution, distortion-free imaging and an extended field of view. It is specially designed for extended use in operating theaters, making it suitable for demanding interventions such as vascular procedures, interventional radiology and hybrid room applications.

Hermes Workstation Multi-modal, vendor-independent image processing workstation for image reconstruction, image fusion, quantification, reporting and archiving.

Nikon A1R confocal microscope (Pegasus) This is a microscope with excellent resolution and contrast and a fast scanning system. This microscope needs upgrades and is under reconsideration. It is located at KI.

Nikon A1Si-STORM microscope (Orion) This is a microscope with excellent contrast, the best possible resolution in light microscopy, and a way to take images of samples with multiple colours. This microscope needs upgrades and is under reconsideration. It is located at KI.

MRI with high-intensity ultrasound (MRI-HIFU) (Philips Ingenia 3T) The 3T MRI equipment produces high-resolution images to be used for clinical purposes and for advanced preclinical research. The integration of High Intensity Focused Ultrasound (HIFU) allows controlled therapeutic intervention under MRI guidance to be used for eliminating, e.g., tumors or pathological conduction pathways in the heart. The therapeutic effect of HIFU can be immediately monitored with continuous MRI scanning. We are currently upgrading this unit, and this is very expensive.

Also, we have a biomechanics lab including a quasistatic mechanical testing machine and a dynamic testing machine. This test equipment can be used for both biomechanical testing of biological tissues as well as prototype testing of materials used in injury preventive projects. We also have two unique test rigs for helmet testing.

The Jonassons center is a KTH infrastructure center, and some funding is associated with this, as well as opportunity to apply for funds. There is an amount of the donation available for further upgrades which can bring the infrastructure a few years forward. In the long term, however, this infrastructure needs a good strategy.

If the number of Cryo-EM users would increase we could aim at establishing a centre for high-contrast and high-resolution cryo-TEM based on microscopes with lower voltage than what is commonly available, 5 to 25 kV for screening specimens and initial studies and around 100 to 200 kV for high resolution studies. This might also be complemented by the matter-free phase plate if it turns out to be feasible. The initial investment for such a centre would be between 10 and 20 million SEK depending on the equipment. Microscopes with lower voltage have been shown to be advantageous for many of the specimens we commonly study and additionally they are economically more sustainable.

3.4. Strategies and organization

a. *Goals for development 5–10 years ahead*

The overarching goal is to 'normalise' MTH from a splintered separate school on a decentral campus to a high-quality, integrated, and well-connected department within KTH. The work on the themes (and restructuring of the educational programs) opens for better integration, and the aim is to get sufficient critical mass to create stable research environments. An increase of external funding of 30% in the shorter term and potentially 50% in the long run is deemed possible and would further build an academic environment.

The unique MTH profile should be further developed towards being the translational research hub where fundamental research, new sensors and technologies, etc, meet the complexity of real health(care) settings. The digitalization research is expected to grow further

The infrastructure currently available gives a good start in further developing into a hub for biomedical imaging research at various scales. However, the KTH perspective needs to be safeguarded as there is historic evidence of the department turning into a service provider more than a research partner. Currently, we are looking into which infrastructures could be developed and should be invested in, as the portfolio is too large to keep up realistically in the long term.

b. *Congruence with university-level goals for research as set out in "A leading KTH - Development Plan 2018-23" and with the school(s) development plan(s) respectively.*

Sustainable development: Focus on preventive health measures (Forsman, Eiken), system cohesion and mental health (Meijer) (GDG 3.4) in 2 themes. Imaging and simulation contribute to GDG 3.6 with the expansion of capacity within validated models of and devices for child and maternal care (Both Smedby and Kleiven group). Improved access to good higher education and safe environments (GDG 4.3 / 4.A) for women and people with a foreign background through an open educational environment (Makerspace and restructuring master programs).
Internationalization: MTH is rapidly internationalizing through newer faculty. The

current limitation lies in the teaching load and network of current employees. Networks from new faculty are important to get more outgoing students.
Gender equality: The faculty at MTH automatically becomes more equal through retirement, but problems remain in informatics and logistics. The research topics engage female students in our research.
Digitization: MTH's profile contributes to the digitization agenda through a system perspective and focus on care and care, and is thus different from other parts of KTH. It is also important that digital technologies do not traditionally reach healthcare: it is the most difficult (and most interesting) sector to change!

c. *Leadership structure and collegial structure*

In line with the general KTH structure, the department is led by a head of department (Sebastiaan Meijer) together with a vice head of department (Matilda Larsson). Meijer is also vice head of school for CBH, thereby safeguarding knowledge about the old STH structure at the new school leadership.

Every division is headed by a head of division, which is the most senior faculty person for all research groups, but for Health Informatics and Logistics which is led by an industry-experienced adjunkt (Anders Cajander), since Meijer is already HoD and vice HoS. The management group consists of the (vice) head of department and the division heads, and is strengthened with the Director of Education for CBH, the head of MedTechLabs, and others where relevant. The management group met every month for the first 2 years of MTH but has now reduced to 4 meetings per semester.

The collegial structure is formalised in two fora since the 2018 reorganisation. The Faculty Group includes all faculty and meets once or twice per semester to discuss perspectives on strategic developments in research related issues and master and PhD education. The faculty group is led by the vice head of department, to facilitate for more free discussion than would happen with the head of department chairing.

The Institutionsforum includes all employees and stipends, and meets once or twice per semester to discuss broader issues related to work environment, profile and strategic developments. This typically takes an afternoon with some joint introduction, break-out in groups and summary in plenary setting.

d. *Strategies for high quality*

Quality assurance is first and foremost the responsibility of the senior faculty in their respective domains. Professors and leading associate professors are primarily responsible for the production of the results in their research environments. Few groups have always been strong and publishing in highly renowned journals, where others have been renewed or disappeared.

The mechanisms through which quality is achieved are fourfold:

- Active encouragement of building healthy research portfolios. The mechanisms of competitive grant applications make that those who get the grants are better positioned to produce quality research. Financially, the department provides co-funding to top up larger external grants.
- Stringent recruiting has been key to improve the quality of all types of personnel. When it comes to faculty recruitment, the merger into the larger CBH school has provided a quality boost in the recruitment process.
- Open Access is encouraged through the CBH school since 2018, and financed

centrally by the school, if not by the KTH Library. This does not yet appear in the statistics.

- Importantly, quality is a culture thing. The ongoing work to slowly change the MTH culture into an active, integrated learning and research environment are therefore paying of when it comes to publications as well. We observe more of our good students doing thesis projects with our better researchers, leading to better theses, but also publications, which in its turn encourages PhD students.

3.5. Interaction between research and teaching

a. *Interaction between research and teaching at all three levels (BSc, MSc, PhD) of education*

MTH has a unique position in that we teach on 4 levels: preparatory year, BSc, MSc and PhD. With around 950 students, divided over 11 programs, the integration between research and teaching is important, but also challenging.

For the preparatory year, the most important thing is to expose our students to a university environment, while teaching them preparatory courses. The new premises in Flemingsberg have given a real boost to the study environment, and the academic atmosphere. Furthermore, discussions between the teachers in this program and others have started on skills and teaching methods to prepare best for further studies.

At the bachelor level, the programs in computer science, electrical engineering and biomedical engineering share many courses. We also teach a program in Technology and Economics. Active work is ongoing to involve more faculty in these programs. The merger of the old teaching-only unit of computer science and electrical engineering with the health care logistics group that was heavily tilted towards research has created new impulses to courses, projects and thesis topics for the computer science and electronics programs.

At the master level, the largest program in biomedical engineering is undergoing a full revision towards problem-based learning. 50% of the teaching will be a project carrier course which will be populated by projects from our faculty. In this way, the broad faculty and research profile of MTH can be utilized to provide interdisciplinary learning, instead of a splintered collection of different courses. The new programs in Sports Technology and the EIT Health labeled Health Innovation program (BHealthSy) are driven by faculty members based upon impact of their research with elite sportsman and health apps, for instance. Interesting collaborations between electronics, imaging and ergonomics are suddenly driving these developments. The revised program in Work, Technology and Health is converted from a practical program (magister) into a full masters, as to give more space to ergonomics research in the program.

At the PhD level, all students are directly engaged in research at one of the 8 groups. An integrated course Technology and Health is mandatory to provide all students with a good grasp of the width of the domain and department. Integrated lectures between senior faculty to cover a topic have been developed since 2017, with great success.

Lastly, a large investment in a research-enabling education asset has been done in 2019. The Flemingsberg Makerspace is a very well equipped set of studios for electrical,

mechanical and computer engineering, with all infrastructures available to produce prototypes that can be used for real-world tests. We observe a massive improvement of the quality of student projects, and engagement of our researchers through this environment.

3.6. Impact and engagement in society

a. *Relevance of research to society at large*

MTH research is extremely societally relevant, with major parts very close to operational reality in the health care sector, or occupational health.

The most fundamental group, structural biotechnology, studies biological structures and develops methods and technology that facilitate these studies. This should in the long run help to find cures for many diseases. All projects have gender specific aspects tied to them, e.g. the inflammatory diseases connected with prostaglandin E2 production as a mediator of pain and fever more commonly occur among men whereas rheumatoid arthritis is more frequent among women. On the other hand, much of our research is equally important for both genders. Specific fields of research we are involved in, e.g. Alzheimers disease, are relevant to an ageing population.

The biomedical imaging and neuronics engineering groups produce technologies that directly benefit the population. Injuries to the head and other body regions account for an enormous monetary cost and induce suffering for the individual and their family. The research at neuronics engineering aims to create research based biomechanical injury prediction tools that can be used for improved prevention of injuries in general. A spin-off in fall-preventing floors receives interests from city councils around Sweden and Europe in installing such safety floors in nursing homes since the awareness of suffering of both elderly and staff is high. Policy makers and stake holders at the national level are also getting a higher awareness about the cost and suffering of fall induced injuries although this process is slower.

Medical image processing methods developed, such as deep-learning-based segmentation, have elicited a great interest from medical practitioners and the med-tech industry as tools for assessing degree or probability of disease (quantitative imaging biomarkers).

Within the theme Digitalisation of Health and Care we address today´s challenges to health care systems and the social world. Worldwide health systems are challenged by epidemiological and demographic transitions, technological innovations, new ways of working when delivering care and not least changing population demands. Growing older populations is the biggest social change of our time together with digital transformations. Since technology is changing, it is proved that images of older technology users still prevail. The TVV division develops methods and theories to meet these challenges. The division is collaborating with investors both SME:s in Sweden and is part of international networks such as Aging2.0. Digitizing society and individuals is no longer about single applications, it is systemic change and an opening to continuous automation that affect practices as well as the

understanding of what is human. The Health Informatics and Logistics division adds a simulation and informatics capability to this, so that actual organizations, particularly Region Stockholm, are concretely supported in their decision making on systemic changes. Engagement in mental health prevention policies is highly relevant and led scientifically by this division.

Since home care, characterized by being homo-social, is populated by women and engineering being male dominated, it makes gender issues present in the entire research. Our research on sustainable work life is again highly relevant to reduce work related injuries, and to keep older people longer in the work force.

b. *Research dissemination beyond academia*

MTH has particularly increased its presence by being part of platforms and collaboration structures, both with industry and the public sector.

Technology in Health care is part of national and international contexts to discuss digitization and later life. Britt Östlund is active in the European discussion on investments of future robotics and invited to the European Economic and Social Committee 2020. She is appointed as member of the Governmental advisory group on Health and Life Science and the advisory group on Ageing research in Sweden. The division has an active blog.

Neuronic engineering have a long tradition of working together with industrial partners such as Autoliv AB, Volvo CC, Saab Automobile and Scania on automotive safety. The computational head and neck models developed at Neuronic engineering are currently being used at those companies for development of innovative safety devices such as new airbag systems.

The division is also involved in national and European actions such as being committee member of COST Action TU1101, towards safer bicycling through optimization of bicycle helmets and usage, member of FIS working group for alpine helmets 2011-2013, and convenor for CEN/TC 158 Working Group 11 - Shock absorption including measuring rotational kinematics. The strategy is to be involved in new biomechanically based test standards committees for helmets and safety flooring ensuring soundness of such safety standards in their capability of capturing innovative protection systems that should reduce the risk of sustaining injuries in practice. Another strategy is to initiate companies based on ideas and patents with innovative protective systems.

Research by our researchers has resulted in patents and patent applications within medical image processing and development of new contrast media.

The division of Environmental Physiology and SAPC has direct impact on development or choice of safety equipment (e.g. anti-G suits, breathing apparatuses) or behavioural strategies (e.g. decompression tables, anti-G straining maneuvers, high-altitude or heat acclimatization techniques) used by pilots, divers and other job categories. In addition, the division regularly support industry (e.g. Saab Aerotech) and authorities (e.g. Swedish Accident Investigation Authority, Swedish Armed Forces) with knowhow, experiments/testing and/or simply by providing special test facilities (centrifuge and pressure chambers).

The division of Health Informatics and Logistics has several faculty persons (e.g. Meijer and Raghothama, and formerly Erlandsson) as part of policy advisor boards

in the regional and national health care world. Meijer and Raghothama are well-integrated with the Health administration of Region Stockholm, and Erlandsson is part of the HL7 standardisation committee.

c. *Sustainability and the United Nations' Sustainable Development Goals (SDG)*

The main MTH SDGs are 3(SDG 3: Good health and well-being) and 8 (SDG 8: Decent work and economic growth), with sideways contributions to 4, 5, 9 and 11. 80-100% of our work is related to these SDGs and therefore related to sustainability, even though the dominant CO2 perspective is not so present.

Since 2015, the changes have been that the research projects acquired, the new positions recruited and internal priorities are just strengthening this health, prevention and work place profile. MTH is proud to have technology, social and system competences and is more and more working together to address the SDGs.

d. *Impact cases*

Here we list five impact cases of recent years:

1: Igelkott AB: Where the Neuronics Engineering research earlier resulted in the well-known MIPS helmet company, a new spin-off Igelkott Golv AB has been created to give the aging society world-wide a product where fall injuries are a known problem. Igelkott Golv AB (http://igelkottgolv.com/) which have used detailed biomechanical models of hip fracture to optimize research based shock absorbing flooring to prevent hip fractures in nursing homes among the elderly.

2: Novamia AB; The research of Chunliang Wang and Örjan Smedby concerning image segmentation methods resulted in a new company, Novamia AB, which owns patents for our methods and produces software products for Swedish and international Med-tech industry. The company currently has one full-time and three part-time employees.

3: Expert advise underlying court cases; Objective analysis of suspected abusive head injuries among children (a k a "shaken baby syndrome"): Diagnosing whether the observed injuries are caused by abuse or other causes such as accidental fall is still a challenge within both the medical and the legal communities and the central question is a biomechanical question: can the described history explain the observed injuries? We reconstructed three well-documented suspected abuse cases using subject-specific FE head models. The results show that the skull fracture patterns in all cases of suspected abuse could be explained by the described accidental fall history, demonstrating the inherent potential of FE analysis for providing biomechanical evidence to aid forensic investigations. Increased knowledge of injury mechanisms in children may have enormous medico-legal implications world-wide. Li, X., Sandler, H., & Kleiven, S. (2019). Infant skull fractures: Accident or abuse?: Evidences from biomechanical analysis using finite element head models. Forensic science international, 294, 173.

4. RAMP: Our projects with risk assessment methods, RAMP, is now deployed world-wide and in use in many factories. More info has been described above.

5. Mental Health: Region Stockholm has engaged the division of Health Informatics and Logistics to base their future Wellbeing Agenda policy on the system methods developed here. Since 2018, the division is part of several projects, leading to a key indicator (measured on the Warwick Wellbeing Scale) now being part of the KPIs for the

region, and to direct policy drafts based upon system dynamics modelling. The division currently drafts the scientific structures for a decision to be taken October 2020 by the Region parliament in which the methods developed become a de facto steering mechanism for any future systemic investment decision.

e. *Structure for increased impact*

The major impact for MTH to have in the future is to be even more integrated with the public health care, nursing, health prevention and work safety bodies. Many of these bodies are notoriously slow and require long trust building and collaboration before any real impact is achieved. The key strategy is therefore to be better represented where it matters, and to build deeper collaborations with Region Stockholm, Karolinska hospital, Karolinska Institute, the Red Cross University College, and other health care partners.

Since 2017, the number of bodies, reference groups, collaboration projects, etc in which MTH researchers are represented is steadily increasing. Much distrust due to old memories of STH have to be overcome, but the results are promising.

When it comes to commercialization, we are proud to say that KTH Innovation has a permanent presence in Flemingsberg since the start of the MakerSpace.

7. Other

a. ***Specifics that the department wishes to mention and describe***

n/a

4. Synergies between Intelligent Systems and Medical Technology & Health

There exist areas of topical overlap between IS and MTH, specifically in medical technology, biosensors and signal processing. Opportunities lay in that the competencies at IS form a potential resource for foundations in medical technology. Our view on this is that:

Most opportunities lay in teaching. However, at KTH, teaching is organised based both on topic and on geography. (IS and MTH are located at different campuses 40 min apart by public transport.) Project courses could be extended, and teacher exchange or coordination between programs could be increased, but this should be done by getting mutual interest rather than top-down decisions.

For research, in the current research environment at KTH and Sweden overall, we do not recommend research to be organised in the line organisation. Rather, excellence results from excellent faculty developing its own research direction. MTH is in a dynamic process towards a clear and quality research profile. There is no longer the ambition to excel even at more fundamental research, and with that, the pathways towards more collaboration are open.

For recruitment, finally, whether to do this based on location is a KTH central political decision.

Today, joint activities and personnel exchange between both departments occur on a natural basis. Examples include:

- Ex IS student Sjoerd Haasl (PhD 2005) became director Clinical Innovation Fellowships at MTH during 2012-2017. Four IS students became fellows under this programme during their PhD studies. Since 2019, Sjoerd is again part-time affiliated with IS as a senior researcher.
- IS Professor Wouter van der Wijngaart was board member of the MTH Centre of Technology in Medicine and Health during 2011-2012.
- Several master students from MTH performed their master thesis at IS. Several students from IS also asked MTH faculty for input on their thesis work.
- Faculty from both IS and MTH have been organising, and teaching at, the annual SJTU-KTH summer school in biomedical technology.
- IS associate Professor Anna Herland is designing a new master-level course in Medical Sensing for the Master's Programme in Innovative Technology for Healthy Living https://www.kth.se/en/studies/master/eit-health/program at MTH. (open for students from both IS and MTH.)