Vetenskapsrådet

Application

2015-03-31

2015-05186 Händel, Peter NT-14

Information about applicant

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Project site: Skolan för elektro- och systemteknik

Information about application

Call name: Forskningsbidrag Stora utlysningen 2015 (Naturvetenskap och teknikvetenskap)

Type of grant: Projektbidrag

Focus: Fri

Subject area:

Project title (english): Smart Wireless Sensors and Networks (SWAN)

Project start: 2016-01-01

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Classification code: 20205. Signalbehandling, 20207. Inbäddad systemteknik, 20299. Annan elektroteknik och elektronik

Keywords: localization, communication and synchronization , ultra wideband radio , wireless sensor networks, distributed signal processing

Funds applied for

Year:	2016	2017	2018	2019
Amount:	1,266,800	1,309,200	1,401,000	1,447,700

Descriptive data

Project info

Project title (Swedish)*

Smarta trådlösa sensorer och nätverk (SWAN)

Project title (English)*

Smart Wireless Sensors and Networks (SWAN)

Abstract (English)*

Accurate localization - of vehicles, robots, humans, and gadgets in both the absolute and relative sense - is an essential component in achieving high levels of autonomy in sensor networks. There are however limitations to existing infrastructure-based solutions such as global navigation satellite systems (GNSS), especially in indoor non line of sight scenarios where such systems perform poorly. In infrastructure-free localization using inertial sensors such as accelerometers and gyroscopes there is an inverse relation between sensor size and localization accuracy, making existing high accuracy solutions inadequate for mass-market applications and miniaturized embedded systems.

The next break trough improvements in local positioning systems will come though the use of collaborative positioning and synchronization by inter-agent communication and sophisticated data analytics for large quantities of low quality sensor data as well as building and infrastructure information. This is one reason that positioning is considered a core part of 5G developments. There will be a need for both infrastructure-free and infrastructure-based localization building on a range of sensor technologies like inertial sensing, vision, and radio ranging, as well as data processing though multi-scale data fusion, advanced and model based spatial-temporal mapping, wireless communications, and distributed processing and learning. Ultra wideband (UWB) radio is an enabling technology utilizing license-exempt spectrum for local connectivity and short-range localization, which is strongly emerging thanks to the technology push (advances within system-on-chip) and 5G market pull.

Within this research proposal, we wish to explore theory and technologies for local localization jointly with communication and synchronization aiming at smart sensors and networks, using tools like optimization theory including robust and stochastic optimization, statistical inference including Bayesian learning and reinforcement learning, wireless communications, and distributed signal processing; and will leverage existing activities within the area.
We are not restricted to a particular application and the research within this proposal is expected to generate general results applicable to a variety of applications. The Ph.D.-students and senior researchers for which funding is applied for, will validate and illustrate the fundamental findings with experimental work employing our in-house developed UWB flexible radio test-bed.

Popular scientific description (Swedish)*

Vi lever i ett samhälle där fler och fler saker blir uppkopplade mot varandra och mot, som vi kallar det idag, nätet eller molnet. Trenden att fler och fler saker blir uppkopplade medför att kraven på funktionaliteten också ökar. I projektet illustrerar vi det framtida behovet av utrustning som denna genom två exempel – det första är ett mobilt exempel vilket inbär att alla noder är rörliga inom ett område. Vi kan tänka oss en svärm av ett hundratal självflygande och självnavigerande små luftfarkoster som flyger i en formation med en gemensam uppgift i åtanke. Kraven är då höga på kommunikation av information mellan de olika flygande objekten; positionering av objekten relativt varandra men också relativt omgivningen, samt att alla objekt har en gemensam uppfattning om tiden, det vill säga använder en gemensam klocka. Ett andra scenario är en gång i en gruva där det finns möjlighet att sätta upp referensnoder som är fast monterade, vilka samarbetar med de rörliga noderna vilka kan vara monterade på fordon eller människor som rör sig i gruvgången. I dessa tuffa industriella miljöer ställs enormt höga krav på tillförlitlighet då systement används för tillämpningar som kan vara kritiska för personalens hälsa och välbefinnande. För att uppfylla kraven behövs forskning inom området anslutna informerade och synkroniserade system för korthållstillämpningar, vilket är det område som projekt SWAN studerar. Genom en kombination av matematisk modellering, datainsamling via experiment i realistiska miljöer, metodutveckling och prestandaanalys så angriper vi problemet och hoppas att generera resultat som inte bara är av grundläggande betydelse för förståelsen, utan även med hög praktiskt relevant som kan tas upp av samhället i stort och leda till nya framsteg för dessa tillämpningar.

Project period

Number of project years*

4

Calculated project time*

2016-01-01 - 2019-12-31

Classifications

Select a minimum of one and a maximum of three SCB-codes in order of priority.

Select the SCB-code in three levels and then click the lower plus-button to save your selection.

SCB-codes*	2. Teknik > 202. Elektroteknik och elektronik > 20205. Signalbehandling
	2. Teknik > 202. Elektroteknik och elektronik > 20207. Inbäddad systemteknik
	2. Teknik > 202. Elektroteknik och elektronik > 20299. Annan elektroteknik och elektronik

Enter a minimum of three, and up to five, short keywords that describe your project.

Keyword 1*

localization, communication and synchronization

Keyword 2*

ultra wideband radio

Keyword 3*

wireless sensor networks

Keyword 4

distributed signal processing

Keyword 5

Ethical considerations

Specify any ethical issues that the project (or equivalent) raises, and describe how they will be addressed in your research. Also indicate the specific considerations that might be relevant to your application.

Reporting of ethical considerations*

Not applicable.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

Smart Wireless Sensors and Networks (SWAN)

Professor Peter Händel

Royal Institute of Technology KTH

STOCKHOLM, Sweden

1 Executive summary

Accurate localization - of vehicles, robots, humans, and gadgets in both the absolute and relative sense - is an essential component in achieving high levels of autonomy in sensor networks. There is however, limitations to existing infrastructure-based solutions such as global navigation satellite systems (GNSS), especially in indoor non line of sight scenarios where such systems perform poorly. In infrastructure-free localization, using inertial sensors such as accelerometers and gyroscopes there is an inverse relation between sensor size and localization accuracy, making existing high accuracy solutions inadequate for mass-market applications and miniaturized embedded systems.

The next breakthrough improvements in local positioning systems will come using collaborative positioning and synchronization by inter-agent communication and sophisticated data analytics for large quantities of low quality sensor data as well as building and infrastructure information. This is one reason that positioning is considered a core part of 5G developments. There will be a need for both infrastructure-free and infrastructure-based localization building on a range of sensor technologies like inertial sensing, vision, and radio ranging, as well as data processing though multi-scale data fusion, advanced and model based spatial-temporal mapping, wireless communications, and distributed processing and learning. Ultra wideband (UWB) radio is an enabling technology utilizing license-exempt spectrum for local connectivity and short-range localization, which is strongly emerging thanks to the technology-push (advances within system-on-chip) and 5G market pull.

Within this research proposal, we wish to explore theory and technologies for local localization jointly with communication and synchronization aiming at smart sensors and networks, using tools like optimization theory including robust and stochastic optimization, statistical inference including Bayesian learning and reinforcement learning, wireless communications, and distributed signal processing; and will leverage existing activities within the area. We are not restricted to a particular application and the research within this proposal is expected to generate general results applicable to a variety of applications. The funding is applied to Ph.D.-students and senior researchers, which will validate and illustrate the fundamental findings with experimental work employing our in-house developed UWB flexible radio test-bed.

A note on the notation: The references in this proposal are found in different bibliographies depending on the first letter in the citation key. Citations starting with “A” are to references found at the end of the project plan. The letters PH are used for publications by Peter Händel (PH) which are reported in the lists of selected publications.

2 Purpose and Aims

Within this proposal, we will explore new research directions motivated by the 5G market pull for short range broad band positioning and communication solutions. The research program is primarily related to our previous and ongoing work on UWB wireless technologies. As we discuss in subsequent sections, basic research in this technology would provide solutions to many challenges in sensor network scenarios.

Through this proposal, we envision smart wireless sensors and networks that are connected, informed, and synchronized. These smart systems find application in various scenarios, e.g., robotic swarms, intelligent transportation systems, first responder situations etc. Smart systems in above mentioned and in similar applications would assist in dynamic maneuvering, efficient resource utilization and will generate information useful for many other purposes. Connected systems would allow for information exchange. Informed systems in such contexts would mean having knowledge of other system's or peer's state, such as position, clock parameters, physical parameters (such as temperature) etc. Wireless time synchronization would allow systems to accomplish synchronized tasks such as time difference of arrival (TDOA) with more maneuvering.

Main approach of the work will be strengthening the smart systems by exploring the domains of dynamic connectivity, message exchanges between nodes through theoretically derived, and experimentally verified novel in-house models, however, the approach is generic in nature. These models are primarily aimed for UWB system measurements. The models are in their infancy but have already leaded to a few breakthroughs and demonstrable ideas of cooperative positioning, synchronization, and communication. Within this research program, we want to continue treading the basic research problems in the area.

With increase in sensing and wireless sensor network infrastructure, message exchange between nodes accomplishes specific tasks of communication, positioning, and distributed processing among many others. In such a scenario, UWB technology can play important role due to its certain unmatched attributes in the time-, frequency-, and power domains, that is:

- large bandwidth (*Giga Hertz range*) provides precision in ranging, hence in positioning.
- precise time measurement (*sub nano-seconds range*) mechanisms enable clock synchronization by precise time of arrival (TOA) measurements.
- Short time stamp (*nano-seconds range*) results in very large update rates for sensor systems. Short time stamp results in high data rate for communications too.
- Low power (*–41 dBm/MHz*) spectral density can provide a layer of connectivity hidden to other wireless systems. Receiver detection by energy efficient hardware (~ 2 *Watts, USB powered*) makes it attractive to sensor network scenarios.

The above-mentioned attributes are essentials for smart short-range wireless systems. Now we will discuss two scenarios, where usage of UWB technology helps in accomplishing our goals.

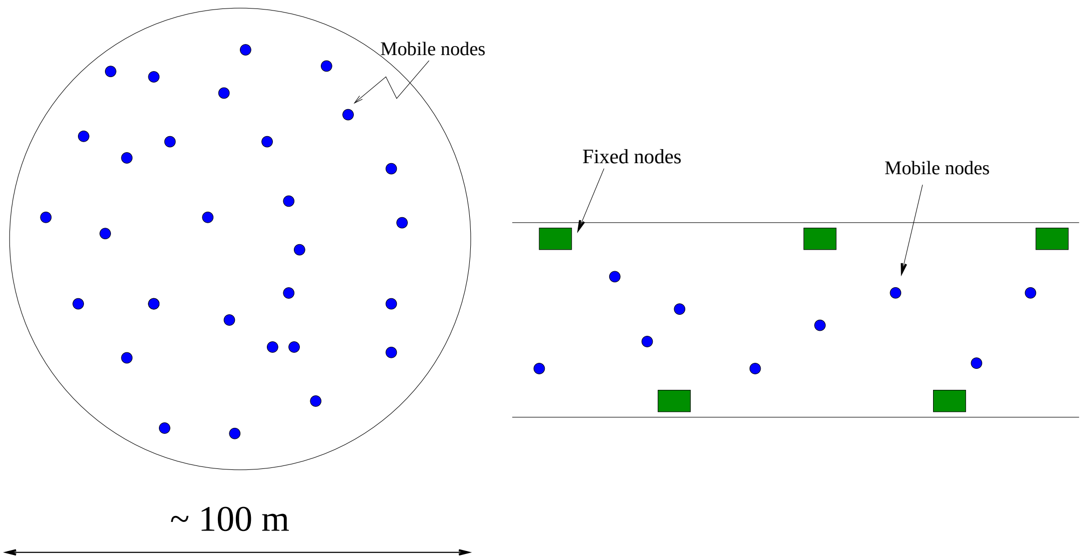

Figure 1: A mobile scenario (left), and an infrastructure scenario (right).

A mobile scenario Consider an area of diameter 100 m with many mobile nodes as shown in Fig. 1. Typically, a minimum distance between any two nodes can be 0.1 m. For e.g., swarm nodes in open spaces, or unmanned air vehicles (UAVs).

UWB wireless solution allows mobility, because a large number of nodes can be served when multiplexed over time due to small time stamp of UWB pulses [PH51, PH66, PH113]. Large bandwidth of UWB pulse results in very accurate position estimates, with accuracy much better than 0.1 m. Schedule based cooperative positioning on top allows dynamic maneuvering by providing relative positions [PH26, PH51, PH66, PH42, PH168, PH104]. In addition, UWB pulse exchanges messages for accomplishing a task at high data rate [PH60, PH120, PH131]. Wireless clock synchronization allows TDOA based positioning and efficient communication [PH33, PH132]. These features are accomplished with low complexity, and low energy hardware of UWB system is very attractive for such purposes [PH40, PH158].

An infrastructure scenario Now we consider usage of smart short range wireless systems in an infrastructure scenario, see Fig. 1. There are a few fixed nodes available in vicinity of a few mobile nodes. For e.g., indoor environment such as office corridors, or harsh environments like mine tunnels [A1].

The fixed nodes can be Wi-Fi access points with/or UWB radios. These nodes will be anchor nodes and would provide absolute positions to mobile nodes [PH51]. The UWB systems will not interfere with wireless infrastructure, as prescribed by spectrum mask regulations worldwide. This would help in developing complementary and supplementary solutions to existing wireless solutions such as Wi-Fi. Further, UWB's precise positioning ability is unique and complementary to other narrowband wireless solutions [PH111, PH51]. Wireless clock synchronization by UWB can supplement capabilities of existing wireless solutions. Precise clock synchronization can be helpful for mitigating packet losses due to collision over wireless [PH33, PH76, PH132].

These smart short range wireless systems can be realized with UWB systems with some assistance from other technologies as well. The latter scenario above suggests fusing other wireless solutions to UWB. Besides, a few other non-wireless technologies can also be fused to improve the performance. In our in-house developed tactical locator (TOR) system (as described on p. 8), UWB radios are fused with inertial sensors to provide precise indoor position information [PH26, PH47, PH49].

In recent years, efforts have been put towards cooperative, adaptive and distributed systems. We will attack the basic research efforts needed to bring these concepts closer to a physical realization through a chosen technology, UWB. The proposed work packages we suggest include suggest basic research towards solving fundamental problems motivated by today's market pull and technology push.

3 Survey of the field including own preliminary results

Relevance of the research on the field can be gauged by recently published papers on the topic in academia. Whereas, our own papers on the topic is testimonial of our interest in exploring basic ideas and applications associated with the technology.

3.1 General survey of the topic, relevance in academia

There are many research groups worldwide exploring effectiveness of UWB systems in various scenarios. The nature of research spans from basic research in theoretical modeling, analysis, performance evaluation to design and experimental research involving building systems and generating data/models from physical processes. Here are a few well-referred articles in very recent past indicating relevance of the research topic considered.

Distributed wireless networks and positioning There has been lot of emphasis on issues related to distributed adaptive sensor networks in literature [A2, A3, A4, A7]. In [A2] and their other publications, authors have been proposing signal processing techniques and analysis for adaptive sensor networks. Authors in [A3] have discussed a very relevant issue of bandwidth-constrained communication for information exchange in sensor networks for information fusion. Distributed positioning based on information sharing and belief propagation has been proposed and analyzed [A4]. Usage of UWB for distributed cooperative positioning is suggested by authors in [A4, A5]. A seminal work suggesting usage of particle filters for positioning and tracking is [A6]. The paper [A7] discusses performance of position estimation in distributed network context. There are only a few experimental works towards cooperative distributed localization. Cooperative localization with UWB radios are reported in [A8, A9].

Network synchronization Synchronization over wireless is attracting researchers [A10, A11, A12]. In [A10], authors have proposed message passing algorithms for network clock synchronization based on Bayesian framework. Authors in [A11] have analyzed distributed clock synchronization over wireless networks. [A12] is a recent survey article on clock synchronization over wireless networks. However, experimental work in this area or validation of wireless clock synchronization algorithms with real world data is rare in literature.

Sensor communications With increasing proposals of message exchanges among sensors to accomplish variety of objectives, it is necessary to find efficient ways of communication among sensors. IEEE 802.15.4a is an UWB based IEEE standard [A15]. Authors in [A13] have discussed various communication technologies suited for machine-to-machine communications. With increase in complexity of adaptive sensor networks, need for more efficient communication technology is ever increasing. The paradigm and framework of communication system optimization is very different in these contexts from traditional cellular communication system design. UWB due to its unique attributes can fit well in such contexts.

3.2 Previous findings by the PI

Positioning and navigation The applicant has an excellent record of accomplishment within positioning and navigation, spanning from the early work on direction-of-arrival estimation (e.g. [A14]) to state-of-the art in-car navigation [PH165]. The latter paper was awarded a Best Survey Paper Award by *IEEE Intelligent Transportation Systems Society*, 2013. Recent achievements by the applicant has been funded by a *VR ICT framework program* with Händel as PI, 2009-12 where the obtained results are relevant both for the general understanding of the area, but also relevant for the deployment of future Safety-of-Life critical systems for first responders. Implementing the basic findings into a real-time high performance demonstrator was done within a Vinnova-DST funded project, 2011-13, which recently was covered by a 6 minutes documentary by Discovery Channel (teaser [1]). A collection of journal papers related to positioning is [PH57, PH62, PH51, PH49, PH47, PH39, PH33, PH26, PH24, PH20, PH11].

In particular, work on UWB-based ranging and positioning has been reported in the journal papers, [PH51, PH66, PH42, PH26], conference papers [PH83, PH85, PH102, PH104, PH105, PH158, PH111, PH113, PH152, PH154, PH158], and the book chapters [PH168].

Communication In the KTH international research assessment 2008 RAE, it was highlighted "*Its (read: within telecommunication) single strongest aspect is the world leading research in communication theory and the physical layer of wireless, and the Access Linnaeus Centre programme.*". The PI has entered the field via his work on characterization of radio frequency components for 4G and 5G, an activity that has evolved from the national Graduate School of Telecommunication (GST). Among other things, he was the supervisor of Professor Magnus Isaksson [PH18, PH19, PH67, PH59, PH64, PH75, PH78, PH81, PH101, PH138, PH141, PH142, PH151, PH155, PH161, PH164], Docent Niclas Björsell [PH4, PH19, PH8, PH9, PH75, PH81, PH101, PH151, PH155, PH164, PH23, PH27, PH28, PH88, PH32, PH34, PH36, PH37, PH45, PH50, PH68, PH69, PH74, PH79, PH87, PH88, PH89, PH92, PH93, PH98, PH99, PH149, PH153, PH156, PH167], David Wisell [PH6, PH71, PH77, PH81, PH151], Per Landin [PH18, PH67, PH59, PH78, PH81, PH101, PH151, PH155, PH161, PH34, PH37], Samer Medawar [PH23, PH88, PH45, PH50, PH74, PH79, PH80, PH88, PH92, PH93, PH118, PH149], Charles Nader [PH81, PH101, PH151, PH155, PH27, PH28, PH32, PH34, PH36, PH37, PH87, PH89, PH98, PH153, PH167], and Sathyaveer Prasad [PH14, PH53, PH54, PH80] that all graduated from GST.

[1] Link `http://youtu.be/ngWabJ2ycAU`

Communication using UWB technology is a new research direction, where initial work includes [PH60, PH120, PH131]. Our gained knowledge from previous efforts will give us a head start exploring UWB communications. Communication using UWB pulses is at a nascent stage in communication research literature. Using our UWB test bed, we intend to develop measurement models that can be useful in developing communication algorithms.

Synchronization The effects of time synchronization errors are considered in [PH33, PH76], and time synchronization and ordering for sensory data [PH90, PH91]. High-resolution time synchronization using UWB technologies are being explored and the solutions will be vital to future short-range smart wireless systems. Some new results in this direction are being finalized.

Joint methods The TOR system makes use of UWB radio as a ranging-communication device (eg. [PH49]), where we have successfully fused UWB and IMU sensors for indoor positioning in an demonstrator reaching a high technology readiness level.

4 Project Description

4.1 Methodology and trade-off between basic and applied research

The methodology applied is an approach where the basic research is driven by stakeholder's needs (a market pull approach). End-users' need are previously reported in survey articles [PH165, PH166] as well as specific publications targeting the need, eg. [PH82, PH103]; targeting intelligent transportation systems and security, respectively.

The basic research is some 80 % of the total research and development activities carried out within the area, where the demonstrator projects are covered by other sources of funding, like Vinnova. During the project, experimental work utilizing our in-house developed UWB test-bed (Sec. 4.4) is envisaged, leading to knowledge from perspectives like safety, security, usability, energy consumption, reliability, and adaptability in daily use. The considered technology plays an important role in e.g. accurate indoor positioning and robust wireless communications for first responder, where the in-house developed tactical locator (TOR) is the playground for demonstrator activities, see Sec 4.5. The work packages are described next, followed by a description of how to secure the human resources needed for the project.

4.2 Work packages, interactions and deliverables

The main purpose and outcome of the project will be in the education of Ph.D.-students, where result should be reported in one to two international conference publications and presentations per year, per student. Typically, at least one submitted journal paper prior to the Licentiate thesis and at least two submitted journal papers prior to the Ph.D. thesis. The involved senior researchers will take responsibility for supervising Ph.D.-students, and accordingly appear as co-authors on the student's papers. They will also have the possibility to pursue their own research, resulting in additional publications; as sole author, or as joint work.

The Department of Signal Processing has extensive international contacts with joint projects, joint publications, research exchanges, *et. cetera* as a result. The PhD-students regularly spend time abroad; as exemplified in the PI's CV, where alumni exchanges are included. Several PhD students earn a double degree, where the Department of Signal Processing currently are under double-degree agreements with Vrije Universitet Brussels, Belgium; Tallin University of Technology, Estonia; and University of Luxembourg. Some recent examples of awarded double degrees are listed in the PI's CV.

We outline work packages (WPs) describing tentative Ph.D.-student projects in some detail, out of a plurality of open problems. These WPs are to be tackled by the enrolled Ph.D.-students.

Work Package 1 (WP1) Research pertaining to precise positioning, wireless clock synchronization, and position dependent communication will be mainstay of this work package. Interplay between accuracy of position estimation, precision of clock synchronization and efficiency of communication systems will be studied and analyzed. We will extend our work of schedule based positioning to more interesting scenarios and in conjunction with wireless clock synchronization. In this work package, we will also extend our work on clock synchronization between two nodes to scalable clock synchronization for any number of nodes. In this context, a large number of nodes in a network can be time synchronized to nano-second precision by appropriate measurements and efficient algorithms. Appropriate measurements to achieve the objective are being developed. Bayesian recursive algorithms updating its state with every measurement will be developed for practical implementations. Theoretical performance bounds will be developed. The ideas and the proposed solutions will be tested with real world data eventually. This work package is the foundation of SWAN and can be considered as core of the solution sphere.

Work Package 2 (WP2) This work package can be considered as crust of the solution sphere. In this package, we will explore additional aspects of short-range smart wireless systems. A few of them are: Non-line-of-sight (NLOS) situations, secure positioning, fusing wireless positioning solutions with complimentary characteristics, scenario based solutions (office space, mines, first responder etc.), variety of information and parameter dissemination issues in short range network and practical implementation aspects of solutions.

We also intend to do comparison of various wireless positioning systems on variety of metrics (performance, energy efficiency, cost, ease of usage etc.). Such a comparison will pave the way to select appropriate solution for specific scenarios.

This work package will also include preparing experimental testbeds. The testbeds will be useful in generating measurements for assisting the researchers in the process of system modelling, testing theoretically designed solutions and to provide deeper insights in functioning of the systems.

4.3 Personnel and recruitment process

The project will be headed by Professor Peter Händel. He will participate 20%. Dr Satyam Dwivedi plays an integral role and will participate 60%. Dr Dwivedi holds a position as Researcher at the Department of Signal Processing. The research personnel will also contribute to other more applied projects part time. That is, provide a good complement to the current proposal and excellent opportunities for international, national and industrial cooperation. In an initial phase, the research personnel will be recruited internally. We have recruited excellent Ph.D.-students whose future project and funding is not yet fully decided. Following admitted PhD-students are in mind:

- Vijaya Parampalli Yajnanarayana. MSc from Illinois Institute of Technology, Chicago USA, with a GPA of 4.0/4.0 and awarded a Highest Standard of Academic Achievement Award. Admitted to the highly competitive *Program of Excellence in Electrical Engineering*[2] at KTH.
- Arun Venkitaraman. Admitted to PhD-studies. M. Sc (Engg.) in EE from the Indian Institute of Science (IISc), Bangalore, India. All India Rank of 10 with a score 1000/1000 and 99.95 percentile in the GATE, 2009 in EE. Admitted to the highly competitive *Program of Excellence in Electrical Engineering* at KTH.

4.4 UWB test-bed

The measurement models are obtained through experiment campaigns using our in-house UWB test-bed. The testbed is built over past few years and is continuously evolving [PH40, PH60, PH97, PH158, PH111, PH158, PH124, PH123]. In the present state we have two versions of UWB testbeds. One is with center frequency of 1 Ghz and another with center frequency of 6.5 GHz. The digital signal processing section consists of Xilinx FPGAs (Spartan-3, Virtex-5, Zynq), depending on objectives. Maximum range between nodes can be up to 30 meters. Range measurement accuracy is around 0.1 m. Various positioning, communication and clock synchronization experiments are being conducted. Signal processing algorithms, which are outcome of our research, are being coded (Verilog HDL) and hosted on these testbeds [PH66, PH51, PH60]. These algorithms make a library of algorithms for our testbed for various purposes. Data/measurement collection from the tested is done over USB and efforts are being made (software development) towards simplifying usage of the testbed.

We have access to an excellent RF measurement laboratory for experimental work. The instrumentation set-up includes high-end instruments as R&S SMU200A, R&S AFQ100A, R&S FSQ26, and R&S FSV13 (9 kHz – 13 GHz) signal analyzer. The set-up allows measurements producing very high quality data with respect to both bandwidth and dynamic range. Efforts have been put to increase the set-up properties with digital signal processing algorithms to stretch the hardware configurations further [PH6, PH71, PH81].

4.5 Tactical Locator (TOR)

The development of the Tactical Locator (TOR) revealed several open research problems within smart sensors and networks, including calibration of IMU-camera clusters [PH63], IMU calibration [PH3] and zero-velocity detection [PH24, PH95]; to mention a few. The stakeholders' (firefighters and first responders) needs and requirements are continuously studied through the aid of workshops and interviews [PH166, PH73, PH82, PH94]. Surveys are

[2] Program of Excellence in Electrical Engineering `www.ee.kth.se`

used to target the research community [PH165, PH166, PH47]. The basic research carried out in SWAN is an integral foundation of future revisions of the TOR system for accurate ranging and robust wireless communication in harsh environments. Over the years, the project has resulted in numerous scientific publications, theses, open source hardware and software, and the TOR demonstrator[3][4].

5 Significance and novelty of the proposal

The significance of the work lies in both its relevance and its approach. The concept and realizing it through UWB technology is relevant to present day research. Further, we claim that our approach of creating measurement models from real world data to build algorithms will help the community in exploring further potentials of UWB technology.

The novelty of perceived solutions through this project can be summarized as:

- *Novel measurement models:* Our in-house experiments have resulted in novel models, which are further used in developing new algorithms [PH51, PH40]. Our approach of deriving models based on experiments will continue and will lead to further new interesting results.
- *New positioning techniques :* Schedule based positioning is a concept proposed by us recently [PH66, PH42, PH51]. Usage of schedules for distributing clock parameters is on the agenda and will be paramount for future synchronized networks.
- *Position dependent communication:* Small footprint of UWB pulses makes it unique to fit in position dependent communication framework [Submitted manuscript]. Optimizing communication schedule and data rates dependent on position of nodes in network will be the goal here. Such results are sought for from sensor networks perspective.
- *Wireless clock synchronization:* Our contributions towards synchronizing clocks among nodes over wireless is in pipeline. It is based on our in-house derived models through experiments [submitted manuscript]. Further work on it towards reaching the goals of the project will get us some pioneering results.
- *Fusing UWB with other sensors:* Fusing UWB with other wireless sensors and other kind of sensors will find its usage in consumer electronics. We have shown fused UWB with IMU sensors in TOR system [PH26, PH49].

[3] System overview `http://youtu.be/dnCyQz5885c`
[4] Full-scale firefighter test, October 2013: `http://youtu.be/VQ0QzFOYtoE`

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[A14] P. Stoica, P. Händel and A. Nehorai, "Improved sequential MUSIC", *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 31, No. 4, October 1995, pp. 1230-1239.

[A15] E. Karapistoli, and F.N. Pavlidou, I. Gragopoulos, and I. Tsetsinas, "An overview of the IEEE 802.15.4a Standard," *IEEE Communications Magazine*, January, 2010.

[A16] G. Panahandeh, S. Hutchinson, P. Händel, and M. Jansson, "Planar-Based Visual Inertial Navigation: Observability Analysis and Motion Estimation," *Journal of Intelligent and Robotic Systems*, Submitted January 2015.

Interdisciplinarity

My application is interdisciplinary

☐

An interdisciplinary research project is defined in this call for proposals as a project that can not be completed without knowledge, methods, terminology, data and researchers from more than one of the Swedish Research Councils subject areas; Medicine and health, Natural and engineering sciences, Humanities and social sciences and Educational sciences. If your research project is interdisciplinary according to this definition, you indicate and explain this here.

Click here for more information

Scientific report

Scientific report/Account for scientific activities of previous project

Not applicable.

Budget and research resources

Project staff

Describe the staff that will be working in the project and the salary that is applied for in the project budget. Enter the full amount, not in thousands SEK.

Participating researchers that accept an invitation to participate in the application will be displayed automatically under Dedicated time for this project. Note that it will take a few minutes before the information is updated, and that it might be necessary for the project leader to close and reopen the form.

Dedicated time for this project

	Role in the project	Name	Percent of full time
1	Applicant	Peter Händel	20
2	Other personnel with doctoral degree	Satyam Dwivedi	60
3	Other personnel without doctoral degree	Vijaya Parampalli Yajnanarayana	40
4	Other personnel without doctoral degree	Arun Venkitaraman	40

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Peter Händel	10	142,000	146,300	150,700	155,200	594,200
2	Other personnel with doctoral degree	Satyam Dwivedi	30	238,600	245,700	253,100	260,700	998,100
3	Other personnel without doctoral degree	Doktorand 1	40	211,600	220,100	245,600	255,400	932,700
4	Other personnel without doctoral degree	Doktorand 2	40	211,600	220,100	245,600	255,400	932,700
	Total			803,800	832,200	895,000	926,700	3,457,700

Other costs

Describe the other project costs for which you apply from the Swedish Research Council. Enter the full amount, not in thousands SEK.

Premises

	Type of premises	2016	2017	2018	2019	Total
1	Kontor och forskningslabb	83,000	86,000	92,000	95,000	356,000
	Total	83,000	86,000	92,000	95,000	356,000

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Resor och traktamente		80,000	80,000	80,000	80,000	320,000
	Total		80,000	80,000	80,000	80,000	320,000

Depreciation costs

Depreciation cost	Description	2016	2017	2018	2019

Total project cost

Below you can see a summary of the costs in your budget, which are the costs that you apply for from the Swedish Research Council. Indirect costs are entered separately into the table.

Under Other costs you can enter which costs, aside from the ones you apply for from the Swedish Research Council, that the project includes. Add the full amounts, not in thousands of SEK.

The subtotal plus indirect costs are the total per year that you apply for.

Total budget

Specified costs	2016	2017	2018	2019	Total, applied	Other costs	Total cost
Salaries including social fees	803,800	832,200	895,000	926,700	3,457,700		3,457,700
Running costs	80,000	80,000	80,000	80,000	320,000		320,000
Depreciation costs					0		0
Premises	83,000	86,000	92,000	95,000	356,000		356,000
Subtotal	966,800	998,200	1,067,000	1,101,700	4,133,700	0	4,133,700
Indirect costs	300,000	311,000	334,000	346,000	1,291,000		1,291,000
Total project cost	1,266,800	1,309,200	1,401,000	1,447,700	5,424,700	0	5,424,700

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

The VR budget covers 50% of the salary cost for the involved KTH senior researchers, for their involvement in the project.

Funding for the PI (10 %) is included. KTH does not provide direct funding for professors' research, that is no, so called, "ämnespott" exists, intended for both supervision but also advancements in the area. Händel regularly publish work as sole or first author, which requires support.

The VR budget covers the salary cost for one PhD-student equivalent (80% activity), divided into two actual students. It is planned that two PhD students employed by KTH will participate in the project but are not to be fully funded through VR. They will be employed (doktorandtjänst) and follow the doctoral salary ladder at KTH. By engaging the students in more targeted research efforts during part of their PhD studies, they will gain valuable experience in addition to the basic research conducted in the VR project. Initially, Vijaya Yajnanarayana and Arun Venkitaraman will be allocated to the project, but over the time of the project a natural renewal of PhD-students may take place.

Travel cost are calculated based on the Department's budget key. A similar budget has been prepared for the rent.

Indirect costs are specified below.
Summa högskolegemensamma: 23,76%
Summa skolgemensamma: 6,33%
Summa avdelningsgemensamma: 7,26%
Summa indirekta kostnader: 37,4%

The budget above is according to the guidelines. Funding for related activities of relevance (including procurement of equipment) will be provided by the accumulated faculty funding (positivt myndigheteskapital) according to Dnr:E-2010-0088) available at the Department of Signal Processing. If a reduced funding is granted (up to a reasonable amount), faculty funding will be secured so that a project can be adapted to the new funding level (omställningskostnader). The research outlined in this application is not covered by other funded or applied for external project grants.

Other funding

Describe your other project funding for the project period (applied for or granted) aside from that which you apply for from the Swedish Research Council. Write the whole sum, not thousands of SEK.

Other funding for this project

Funder	Applicant/project leader	Type of grant	Reg no or equiv.	2016	2017	2018	2019

CV and publications

CV

Curriculum Vitae – Peter Händel (born: 1962)

1. Higher education degree

Engineering Physics (*civ.ing. (F))*, Uppsala University, Sweden (1987).

2. Doctoral degree

Ph.D. in Automatic Control (main supervisor, T. Söderström, title: Estimation methods for narrow-band signals), Uppsala University, Sweden (1993)

3. International PostDoc

• Department of Signal Processing, Tampere University of Technology, Finland. (Supervisor: J. Astola). Funded by TFR. (Aug 1996 – June 1997)
• Institute of Information Theory and Automation, Prague, Czech Republic. (Supervisor: V. Kucera). Funded by KVA. (June 1997 – July 1997)

4. Docent appointments and professional qualification

• Docent in Automatic Control, Uppsala University, Sweden (1996)
• Eur-ing, European Federation of National Engineering Associations (1996)
• Docent in Information Technology, Tampere University of Technology, Finland (1998)

5. Present position

Professor of Signal Processing, (percentage research allocated for the position is not specified), KTH Royal Institute of Technology, Jan 2006 –

6. Previous positions and periods of appointment

• Associate Professor of Signal Processing (*universitetslektor*). (1997 – 2005)
• Ericsson Radio Systems AB, Research and Development, Kista, Sweden. (1993 – 1997)

6b. Previous affiliated positions and periods of appointment

• Visiting Professor, Indian Institute of Science (IISc), India. (Sep 2010 – Nov 2010)
• Different appointed positions inc. *Gästprofessor*, University of Gävle, Sweden. (2007–2013)
• Associate Director of Research, Swedish Defence Research Agency (FOI). (2000–2006)

8a. Main supervisor KTH (*huvudhandledare*)
1. Björn Völcker, Ph.D. April 2002. (Now at Google Inc.) (*co-supervisor*)
2. Johan Falk, Lic.Eng. December 2004. (Now at Swedish Defence Research Agency, FOI)
3. Tomas Andersson, Ph.D. June 2005. (Now at Recco AB)
4. Henrik Lundin, Ph.D. December 2005. (Now at Google Inc.)
5. *Professor* Magnus Isaksson, Ph.D. May 2007. (Now at the University of Gävle)
6. *Docent* Niclas Björsell, Ph.D. November 2007. (Now at the University of Gävle)

7. David Wisell, Ph.D. December 2007. (Now at Ericsson AB, China)
8. Isaac Skog[5], Ph.D. January 2010. (Now at KTH)
9. Per Landin[6], Ph.D. June 2012. (Now at Ericsson AB)
10. Samer Medawar[7], Ph.D. June 2012. (Now at Alten Sweden AB)
11. Charles Nader[8], Ph.D. August 2012. (Now at Nokia Solutions and Networks, Germany)
12. Sathyaveer Prasdad, Ph.D. March 2013. (Now at PCS)
13. Dave Zacharia, Ph.D. May 2013. (Now at Uppsala University) (*co-supervisor*)
14. John-Olof Nilsson[9], Ph.D. November 2013. (Now at KTH)
15. Ghazaleh Panahandehnigjeh,[10][11] Ph.D. April 2014. (*co-supervisor*) (at Volvo Cars AB)
16. Prasadh Ramachandran, LicEng. February 2015 . (Now at Pulse OY, Finland)

8b. Ongoing PhD-students (*huvudhandledare*)

17. *LicEng* Efrain Zenteno (scheduled June 2015) (MSc: University of Gävle, Sweden)
18. Senay Negusee (scheduled June 2015) (MSc: Blekinge Institute of Technology, Sweden)
19. Vijaya Parampalli Yajnanarayana (MSc: Illinois Institute of Technology, USA)
20. *LicEng* Shoaib Amin (MSc: University of Gävle, Sweden)
21. Nima Najari Moghadam (MSc: KTH, Sweden)
22. Arun Venkitaraman (MSc: Indian Institute of Science, India)
23. Mahmoud Alizadeh (MSc: Lund University, Sweden)
24. Zain Ahmed Kahn (MSc: Technical University Ilmenau, Germany)
25. Farid Bonawide (MSc: KTH)
26. Johan Wahlström (MSc: KTH)
27. Robin Larsson (MSc: KTH)

8c. PostDocs

2009-2010: Alessio de Angelis (Ph.D. 2009, University of Perugia, Italy)
2010-2012: Isaac Skog (Ph.D. 2010, KTH)
2011-2013: Satyam Dwivedi (Ph.D. 2011, Indian Institute of Science, India)
2013– Christian Schuldt (Ph.D. 2012, Blekinge Institute of Technology, Sweden)
2014– John-Olof Nilsson (Ph.D. 2013, KTH)

9. Awards, etc

1995 *Best Paper Award*, UTIA, Academy of Sciences of the Czech Republic
1999 Junior Individual Grant (JIG) by the Swedish Foundation for Strategic Research (SSF)
2000 *Best Paper Award*, UTIA, Academy of Sciences of the Czech Republic
2006 ACCESS Linnaeus Centre, founding faculty
2008 Swedish traffic safety award *The Golden Moose*, `www.guld-algen.se`
2009 Main applicant VR IKT-ramprogram
2013 *Best Survey Paper Award* (2000–09), *IEEE Trans. on Intelligent Transportation Systems*

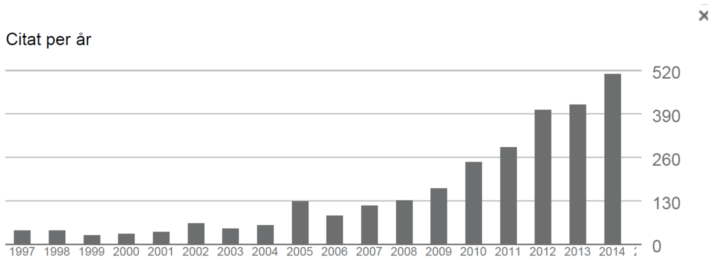
[5] Spent 5 months at University of Calgary, Canada
[6] Spent 6 months at Vrije Universiteit Brussel VUB, Brussels, Belgium – Double degree KTH–VUB
[7] Spent 5 months at Stanford, USA
[8] Spent 6 months at Vrije Universiteit Brussel VUB, Brussels, Belgium – Double degree KTH–VUB
[9] Spent 4 months at IISc, India
[10] Spent 5 months University of Illinois Urbana Champaign
[11] Spent 5 months at University of Minnesota, USA

Publication list

Peter Händel – Publications 2007 –

Citation statistics and top-five papers

Source: Google Scholar, March 19, 2015 - no manual adjustments. Number of citations: 3005 (since 2010: 1956).



Top-cited journal papers:

1 [PH165][12]: *Number of citations: 216*, published: 2009

2 [PH2]: *Number of citations: 121*, published: 2000

- ([PH3]: *Number of citations: 114*, published: 2006 - conference paper)

3 [PH24]: *Number of citations: 106*, published: 2010

- (US Patent 5,943,429 : *Number of citations: 101*, published: 1999 – US Patent)

4 [PH166]: *Number of citations: 83*, published: 2011

5 [PH1]: *Number of citations: 71*, published: 1994

Top-five most relevant journal papers for the application:

[PH66] Joint ranging and clock parameter estimation by wireless round trip time measurements, *IEEE Journal on Selected Areas in Communications, special issue on Location-Awareness For Radios And Networks*

[PH60] Spectral efficient IR-UWB communication design for low complexity transceivers, *EURASIP Journal on Wireless Communications and Networking*

[PH51] Schedule-based sequential localization in asynchronous wireless networks, *EURASIP Journal on Advances in Signal Processing, special issue on Signal Processing Techniques for Anywhere, Anytime Positioning*

[PH42] Self-localization of asynchronous wireless nodes with parameter uncertainties, *IEEE Signal Processing Letters*

[PH40] Characterization of a flexible UWB sensor for indoor localization, *IEEE Transactions on Instrumentation and Measurement*

[12] IEEE ITS Society Best Survey Paper Award, 2013. See “The Top and the Best: Toward Excellence in ITS Research and Development,” *Intelligent Transportation Systems, IEEE Transactions on*, Volume: 14 , Issue: 3, 2013.

References

1. Peer-reviewed original articles

Older top-cited papers

[PH1] P. Händel and A. Nehorai, “Tracking analysis of an adaptive notch filter with constrained poles and zeros", *IEEE Transactions on Signal Processing*, Vol. 42, No. 2, February 1994, pp. 281-291. *number of citations: 71*

[PH2] P. Händel, “Properties of the IEEE-STD-1057 four-parameter sine wave fit algorithm”, *IEEE Transactions on Instrumentation and Measurement*, Vol. 49, No. 6, pp. 1189-1193, December, 2000. *number of citations: 121*

[PH3] I. Skog and P. Händel, “Calibration of a MEMS inertial measurement unit”, *IMEKO XVIII World Congress*, September 17-22, 2006, Rio de Janerio, Brazil. *number of citations: 116*

2007

[PH4] N. Björsell and P. Händel, “Truncated Gaussian noise in ADC histogram tests", *Measurement*, vol. 40, pp. 36-42, 2007. *number of citations: 11*

[PH5] P. Händel, “Power spectral density error analysis of spectral subtraction type of speech enhancement methods", *EURASIP Journal on Advances in Signal Processing*, vol. 2007, Article ID 96384, 9 pages, 2007. *number of citations: 3*

[PH6] D. Wisell, D. Rönnow and P. Händel, “A technique to extend the bandwidth of a power amplifier test-bed”, *IEEE Transactions on Instrumentation and Measurement*, Vol. 56, No. 4, August 2007, pp. 1488-1494. *number of citations: 27*

2008

[PH7] N. Björsell and P. Händel, “Histogram tests for wideband applications”, *IEEE Transactions on Instrumentation and Measurement*, Vol. 57, No. 1, January 2008, pp. 70–75. *number of citations: 7*

[PH8] N. Björsell, P. Suchanek, P. Händel and D. Rönnow, “Measuring the Volterra kernels of analog to digital converters using a stepped three-tone scan”, *IEEE Transactions on Instrumentation and Measurement*, Vol. 57, No. 4, April 2008, pp. 666-671. *number of citations: 33*

[PH9] N. Björsell and P. Händel, “Achievable ADC performance by post-correction utilizing dynamic modeling of the integral nonlinearity”, *EURASIP Journal on Advances in Signal Processing*, Volume 2008, Article ID 497187, 10 pages, doi:10.1155/2008/497187. *number of citations: 19*

[PH10] P. Händel, “Parameter estimation employing a dual channel sinewave model under a Gaussian assumption,” *IEEE Transactions on Instrumentation and Measurement*, Vol. 57, No. 8, August 2008, pp. 1661-1669, doi:10.1109/TIM.2008.923782. *number of citations: 34*

2009

[PH11] P. Händel, Y. Yao, N. Unkuri, I. Skog, "Far infrared camera platform and experiments for moose early warning systems," *JSAE Transactions*, Vol. 40, No. 4, July 2009, pp. 1095-1099. *number of citations: 1*

[PH12] H.F. Lundin, P. Händel and M. Skoglund, "Bounds on the performance of analog-to-digital converter look-up table post-correction", *Measurement*, vol. 42, pp. 1164-1175, 2009. doi:10.1016/j.measurement.2008.02.007. *number of citations: 4*

[PH13] P. Händel, "Discounted least-squares gearshift detection using accelerometer data," *IEEE Transactions on Instrumentation and Measurement*, Vol. 58, No. 12, December 2009, pp. 3953-3958, doi:10.1109/TIM.2009.2020844. *number of citations: 13*

[PH14] P. Händel, S. Prasad, C. Beckman, "Maximum likelihood estimation of reverberation chamber direct-to-scattered ratio," *Electronics Letters*, Vol. 45, No. 25, December 2009. *number of citations: 8*

2010

[PH15] P. Händel, B. Enstedt and M. Ohlsson "Combating the effect of chassis squat in vehicle performance calculations by accelerometer measurements", *Measurement*, Vol. 43, pp. 483-488, doi: 10.1016/j.measurement.2009.12.019, 2010. *number of citations: 5*

[PH16] J. Trehag, P. Händel and M. Ögren, "On-board estimation and classification of a railroad curvature", *IEEE Transactions on Instrumentation and Measurement*, Vol. 59, No. 3, March 2010, pp. 653-660, doi:10.1109/TIM.2009.2025082. *number of citations: 7*

[PH17] P. Händel and P. Zetterberg, "Receiver IQ imbalance: tone tests, sensitivity analysis, and the universal software radio peripheral," *IEEE Transactions on Instrumentation and Measurement*, Vol. 59, No. 3, March 2010, pp. 704-714, doi:10.1109/TIM.2009.2025989. *number of citations: 14*

[PH18] P.L. Landin, M. Isaksson and P. Händel, "Parameter extraction and performance evaluation method for increased performance in RF power amplifier behavioral modeling," *International Journal of RF and Microwave Computer-Aided Engineering*, Vol. 20, Issue 2, March 2010, pp. 200-208, doi: 10.1002/mmce.20422, 2010. *number of citations: 4*

[PH19] N. Björsell, M. Isaksson, P. Händel, D. Rönnow,"Kautz-Volterra modelling of analogue-to-digital converters," *Computer Standards & Interfaces*, in Vol. 32, No. 3, March 2010, pp. 126-129. doi:10.1016/j.csi.2009.11.007. *number of citations: -*

[PH20] I. Skog and P. Händel, "Synchronization by two-way message exchanges: Cramér-Rao bounds, approximate maximum likelihood, and offshore submarine positioning," *IEEE Transactions on Signal Processing*, Vol. 58, No. 4, April 2010, pp. 2351-2362, doi:10.1109/TSP.2010.2040669 *number of citations: 16*

[PH21] L. Anttila, P. Händel and M. Valkama, "Joint mitigation of power amplifier and modulator impairments in wideband direct-conversion transmitters, " *IEEE Transactions on Microwave Theory and Techniques*, Vol. 58, No. 4, April 2010, pp. 730-739, doi: 10.1109/TMTT.2010.2041579. *number of citations: 71*

[PH22] P. Händel, "Amplitude estimation using IEEE-STD-1057 three-parameter sine wave fit: statistical distribution, bias and variance," *Measurement*, Vol. 43, Issue 6, July 2010, pp. 766-770, doi: 10.1016/j.measurement.2010.02.007. *number of citations: 9*

[PH23] S. Medawar, P. Händel, N. Björsell and M. Jansson "Input-dependent integral nonlinearity modeling for pipelined analog-digital converters," *IEEE Transactions on Instrumentation and Measurement*, Vol. 59, No. 10, October 2010, pp. 2609-2620, doi:10.1109/TIM.2010.2045551,

2010. *number of citations: 15*

[PH24] I. Skog, P. Händel, J-O. Nilsson and J. Rantakokko “Zero-velocity detection – an algorithm evaluation,” *IEEE Transactions on Biomechanical Engineering*, Vol. 57, No. 11, November 2010, pp. 2657-2666, doi:10.1109/TBME.2010.2060723, 2010. *number of citations: 107*

[PH25] L. Anttila, P. Händel, O. Mylläri and M. Valkama, “Recursive learning based joint digital predistorter for power amplifier and I/Q modulator impairments,” *International Journal of Microwave and Wireless Technologies*, Vol. 2, Issue 02, pp. 173-182, 2010, doi:10.1017/S1759078710000280. *number of citations: 5*

[PH26] A. De Angelis, J-O. Nilsson, I. Skog, P. Händel and P. Carbone, “Indoor positioning by ultra-wide band radio aided inertial navigation,” *Metrology and Measurement Systems*, Vol. XVII, No. 3, pp. 447-460, 2010. *number of citations: 38*

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[PH27] C. Nader, P. Händel, N. Björsell, “Peak-to-average power reduction of OFDM signals by convex optimization: experimental validation and performance optimization,” *IEEE Transactions on Instrumentation and Measurement*, Vol. 60, No. 2, February 2011, pp. 473-479, doi:10.1109/TIM.2010.2050360, 2010. *number of citations: 13*

[PH28] C. Nader, N. Björsell, P. Händel, “Unfolding the frequency spectrum for undersampled wideband data,” *Signal Processing*, Vol. 91, Issue 5, May 2011, pp. 1347-1350 doi:10.1016/j.sigpro.2010.12.013. *number of citations: 1*

[PH29] S. Medawar, P. Händel, N. Björsell and M. Jansson “Postcorrection of pipelined analog-digital converters based on input-dependent integral nonlinearity modeling,” *IEEE Transactions on Instrumentation and Measurement*, Vol. 60, No. 10, October 2011, pp. 3342-3350. doi:10.1109/TIM.2011.2126870 *number of citations: 15*

[PH30] J. Fritzin, Y. Jung, P.N. Landin, P. Händel, M Enqvist and A. Alvandpour, “Phase predistortion of a class-D outphasing RF amplifier in 90nm CMOS,” *IEEE Transactions on Circuits and Systems - Part II*, Vol. 58, No. 10, October 2011, pp. 642-646. doi:10.1109/TCSII.2011.2164149. *number of citations: 21*

[PH31] C.R. Rojas, P. Zetterberg, and P. Händel, “Transceiver inphase/quadrature-imbalance, ellipse fitting, and the universal software radio peripheral,” *IEEE Transactions on Instrumentation and Measurement*, Vol. 60, No. 11, November 2011, pp. 3629-3639. doi:10.1109/TIM.2011.2138290 *number of citations: 8*

[PH32] C. Nader, W. Van Moer, K. Barbé, N. Björsell and P. Händel, “Harmonic sampling and reconstruction of wide-band undersampled waveforms: Breaking the code,” *IEEE Transactions on Microwave Theory and Techniques*, Vol. 59, No. 11, November 2011, pp. 2961-2969. doi:10.1109/TMTT.2011.2161882 *number of citations: 6*

[PH33] I. Skog and P. Händel, “Time synchronization errors in loosely coupled GPS-aided inertial navigation systems,” *IEEE Transactions on Intelligent Transportation Systems*, Vol. 12, No. 4, December 2011, pp. 1014-1023. doi:10.1109/TITS.2011.2126569 *number of citations: 18*

[PH34] C. Nader, P.N. Landin, W. Van Moer, N. Björsell, P. Handel, “Performance evaluation of peak-to-average power ratio reduction and digital pre-distortion for OFDM baseded systems,” *IEEE Transactions on Microwave Theory and Techniques*, Vol. 59, No. 12, Dec. 2011, pp. 3504-3511, doi:10.1109/TMTT.2011.2170583. *number of citations: 22*

2012

[PH35] S. Negusse and P. Händel, "The dual channel sinewave model: Co-prime sparse sampling, parameter estimation, and the Cramér-Rao bound," *Measurement*, Vol. 45, No. 9, Nov. 2012, pp. 2254-2263. http://dx.doi.org/10.1016/j.measurement.2012.03.021 *number of citations: 2*

[PH36] C. Nader, W. Van Moer, N. Björsell, K. Barbé, P. Händel,"Reducing the analog and digital bandwidth requirements of RF receivers for measuring periodic sparse waveforms," *IEEE Transactions on Instrumentation and Measurement*, Vol. 61, No. 11, Nov. 2012, pp. 2960-2971, doi:10.1109/TIM.2012.2203729. *number of citations: 6*

[PH37] C. Nader, P.N. Landin, W. Van Moer, N. Björsell, P. Handel, D. Rönnow, "Peak-power controlling technique for enhancing digital pre-distortion of RF power amplifiers," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 60, No. 11, Nov. 2012, pp. 3571-3581, doi:10.1109/TMTT.2012.2213836 *number of citations: 6*

[PH38] P.N. Landin, W. Van Moer, M. Isaksson, P. Handel, "Peak-power controlled digital predistorters for RF power amplifiers," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 60, No. 11, Nov. 2012, pp. 3582-3590, doi:10.1109/TMTT.2012.2213830. *number of citations: 3*

[PH39] D. Zachariah, I. Skog, M. Jansson and P. Händel, "Bayesian Estimation with Distance Bounds," *IEEE Signal Processing Letters*, Vol. 19, No. 12, Dec. 2012, pp. 880-883, doi:10.1109/LSP.2012.2224865. *number of citations: 9*

2013

[PH40] A. De Angelis, S. Dwivedi, P. Händel, "Characterization of a Flexible UWB Sensor for Indoor Localization," *IEEE Transactions on Instrumentation and Measurement*, Vol. 62, No. 5, May. 2013, pp. 905-913, 2013. doi:10.1109/TIM.2013.2243501. *number of citations: 15*

[PH41] G. Panahandeh, N. Mohammadiha, A. Leijon, and P. Händel, "Continuous Hidden Markov Model for Pedestrian Activity Classification and Gait Analysis," *IEEE Transactions on Instrumentation and Measurement*, Vol. 62, No. 5, May. 2013, pp. 1073-1083, 2013. doi: 10.1109/TIM.2012.2236792. *number of citations: 17*

[PH42] D. Zachariah, A. De Angelis, S. Dwivedi and P. Händel, "Self-Localization of Asynchronous Wireless Nodes with Parameter Uncertainties," *IEEE Signal Processing Letters*, Vol. 20, No. 6, May. 2013, pp. 551-554, 2013. doi: 10.1109/LSP.2013.2255592. *number of citations: 6*

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[PH151] C. Nader, P. Landin, N. Björsell, M. Isaksson, D. Wisell, P. Händel, O. Andersen and N. Keskitalo, “Wideband power amplifier charaterization by undersampling: Zu-Frank sampling theorem," presented at *The Conference on RF Measurement Technology, for State of The Art Production and Design*, Gävle, Sweden, October 6-7, 2009.

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[PH161] S. Amin„ E. Zenteno, P.N. Landin, D. Rönnow, M. Isaksson, and P. Händel, “Noise impact on the identification of digital predistorter parameters in the indirect learning architecture,” *Swedish Communication Technologies Workshop (Swe-CTW 2012)*, Lund, 24-26 October 2012.

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[PH164] D. Rönnow, N. Björsell, J. Chilo, P. Händel, M. Isaksson, and W. Van Moer “Radio Measurement Technology for Characterization of Nonlinear Devices and Industrial Radio Environments", *GigaHertz Symposium 2014*, March 11-12, Gothenburg.

3. Peer-reviewed review articles

[PH165] I. Skog and P. Händel, “In-car positioning and navigation technologies – a survey,” *IEEE Transactions on Intelligent Transportation Systems*, Vol. 10, No. 1, March 2009, pp. 4-21, doi:10.1109/TITS.2008.2011712.

[PH166] J. Rantakokko, J. Rydell, P. Strömbäck, P. Händel, J. Callmer, D. Törnqvist, F. Gustafsson, M. Jobs, M. Grudén, “Accurate and reliable soldier and first responder indoor positioning: Multisensor systems and cooperative localization,” *IEEE Wireless Communications*, April, 2011, pp. 10-18, doi:10.1109/MWC.2011.5751291.

[PH167] C. Nader, W. Van Moer, N. Björsell, P. Händel, “Wide-band radio frequency measurements: from instrumentation to sampling theory,” *IEEE Microwave Magazine*, March/April, 2013, pp. 85-98. doi: 10.1109/MMM.2012.2234643

4. Books and book chapters

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[PH169] I. Skog and P. Händel, *In-Car Navigation Basics*, Chapter 17 in Handbook of Intelligent Vehicles, Springer-Verlag London Ltd., 2012, ISBN 978-0-85729-084-7, DOI 10.1007/978-0-85729-085-4.

[PH170] H. Lundin and P. Händel, *Look-Up Tables, Dithering and Volterra Series for ADC Improvements*, Chapter 8 in *Design, Modeling and Testing of Data Converters*, Signals and Communication Technology, DOI: 10.1007/978-3-642-39655-7_8, Springer-Verlag Berlin Heidelberg, 2014.

[PH171] J. Ohlsson, P. Händel, S. Han and R. Welch, *Process Innovation with Disruptive Technology in Auto Insurance: Lessons Learned from a Smartphone Based Insurance Telematics Initiative*, Chapter 7 in *BPM – Driving Innovation in a Digital World*, Springer International Publishing Switzerland, DOI 10.1007/978-3-319-14430-6_7

5. Patents

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[PH173] M. Ohlsson, P. Händel, J. Ohlsson, and I. Skog, “Larm-anordning i fordon´´, Swedish patent application 1130079-5, September, 2011. (approved)

[PH174] P. Händel, M. Ohlsson, J. Ohlsson, and I. Skog, “Avläsning och central lagring av mätarställning´´, Swedish patent application 1230004-2, January, 2012. (approved)

[PH175] P. Händel, M. Ohlsson, I. Skog, and J. Ohlsson, “Bestämning av aktivitetsgrad hos portabel elektronisk utrustning´´, Swedish patent application 1230015-8, February, 2012. (approved)

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[PH177] P. Händel, I. Skog, M. Ohlsson, and J. Ohlsson, “Anordning för att bestämma identitet hos ett motorfordon´´, Swedish patent application, 1230137-0, November, 2012.

[PH178] I. Skog, P. Händel, M. Ohlsson, and J. Ohlsson, “Beräkning av accelerationssignal utifrån hastighetsmätning´´, Swedish patent application, 1330082-7, June, 2013.

6. Open access computer programs that you have developed

[PH179] IR-EE-SB 2010:013 Author: Peter Händel, Title: Matlab software for IQ-imbalance determination Date: March 2010.Available at `www.ee.kth.se`.

CV

Name: Peter Händel	**Doctorial degree:** 1993-06-15
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Research education

Dissertation title (swe)		
Estimation methods for narrow-band signals		
Dissertation title (en)		
Estimation methods for narrow-band signals		
Organisation	**Unit**	**Supervisor**
Uppsala universitet, Sweden Sweden - Higher education Institutes	Inst för informationsteknologi	Torsten Söderström
Subject doctors degree	**ISSN/ISBN-number**	**Date doctoral exam**
20202. Reglerteknik	91-628-0845-1	1993-06-15

Publications

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Händel, Peter has not added any publications to the application.

Register

Terms and conditions

The application must be signed by the applicant as well as the authorised representative of the administrating organisation. The representative is normally the department head of the institution where the research is to be conducted, but may in some instances be e.g. the vice-chancellor. This is specified in the call for proposals.

The signature*from the applicant*confirms that:

- the information in the application is correct and according to the instructions form the Swedish Research Council
- any additional professional activities or commercial ties have been reported to the administrating organisation, and that no conflicts have arisen that would conflict with good research practice
- that the necessary permits and approvals are in place at the start of the project e.g. regarding ethical review.

The signature *from the administrating organisation* confirms that:

- the research, employment and equipment indicated will be accommodated in the institution during the time, and to the extent, described in the application
- the institution approves the cost-estimate in the application
- the research is conducted according to Swedish legislation.

The above-mentioned points must have been discussed between the parties before the representative of the administrating organisation approves and signs the application.

Project out lines are not signed by the administrating organisation. The administrating organisation only sign the application if the project outline is accepted for step two.

Applications with an organisation as applicant is automatically signed when the application is registered.