Application

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Information about application

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Descriptive data

Project info

Project title (Swedish)*

Modellering och skattning av den underliggande dynamiken för brytpunkterna i regimskiftesmodeller

Project title (English)*

Modelling and learning of latent switching processes in change point detection problems

Abstract (English)*

Many research field deal with so-called change point detection problems in which one tries to discover critical time events at which
the statistical behaviour changes in one or several time series. One can think of a set of underlying processes, below called switching processes, that are responsible for generating the change points and it is often important to learn the properties of these
processes since these will potentially help reveal what the actual physical cause of the change points is.
This project concern developing methods for learning the parameters and the model structure for such underlying switching
processes. The key in the approach is to use multiple time series since this will provide us with more high quality data and thus
significantly improve the possibilities for building accurate models for the switching processes.
Bayesian methods such as structural EM and variational methods will be used for the estimation and structural learning and those will be benchmarked against Markov Chain Monte Carlo based methods. In particular will we use recently developed algorithms that allow us to determine the probability that one change point is common to two series or not. This algorithm is a generalisation of the method developed by Fearnhead in 2005, to involve two time series.
Succeeding with this research would provide researcher in many diverse fields, such as climate research and finance, with new
improved tools that will help discovering the underlying causes of the change point events.

Popular scientific description (Swedish)*

Inom åtskilliga forskningsområden ägnar man sig åt att analysera tidsserier av uppmätta data och en vanlig uppgift är att leta efter
mer eller mindre abrupta förändringar i beteende i dessa. Det kan röra sig om förändringar i temperaturmedelvärden inom klimatforskning, förändringar i dynamiken i aktiekurser med mera. Det kan många gånger röra sig om förändringar som påverkar data i flera tidsserier mer eller mindre samtidigt, till exempel att korrelationen mellan data i två serier plötsligt ändras. Tidpunkterna för dessa förändringar förväntas ofta ge viktig information om vilken den underliggande faktor är som har orsakat dessa. Mer allmänt är det intressant att kunna fånga dynamiken i den underliggande processen, dvs skapa statistiska modeller för att beskriva beteendet hos de bakomliggande faktorerna. Denna dynamik förväntas ge oss värdefull information om vilken typ av bakomliggande process som styr beteendet hos de brytpunkter vi observerar.

En sak som komplicerar analysen är att de observerade tidserierna ofta påverkas av flera bakomliggande faktorer samtidigt. Många gånger är dessa faktorer tämligen frikopplade från varandra och de kan då vara svårt att sortera ut vilken av förändringspunkterna som orsakas av vilken av faktorerna. Det sammanlagda förändringsmönstret orsakat av flera oberoende faktorer kan ofta uppfattas som slumpmässigt och komplicerat även i fall då beteendemönstret hos var och en av de bakomliggande faktorerna är relativt enkelt. Om vårt mål är är att skapa statistiska modell för att beskriva beteendet hos de bakomliggande faktorerna så kan möjligheterna att lyckas med detta förbättras radikalt om vi studerar flera tidsserier kollektivt. Vi kan leka med tanken att vissa bakomliggande faktorer endas påverkar ett litet fåtal av serierna medan andra påverkar ett större antal. Det kan till exempel röra sig om mätdataserier upptagna i ett geografiskt område där vissa bakomliggande faktorer påverkar endast lokalt medan andra har en mer global inverkan. Sekvensen av förändringar i en enskild tidsserie kan te sig komplicerad men genom att notera vilka mätserier som uppvisar samtidiga förändringar så kan vi börja sortera ut vilka förändringstillfällen som hör ihop genom att de har som gemensam egenskap att de uppträder i samma uppsättning tidsserier. På detta sätt har vi möjlighet att bringa ordning i serien av förändringstidpunkter och detta torde vi ha stor nytta av när vi skapar statistiska modeller för att beskriva tidsdynamiken hos de bakomliggande faktorerna.

I det föreslagna projektet kommer vi att utveckla algoritmer och metodik för att utnyttja multipla tidsserier för att avgöra när vi har
abrupta förändringar i tidsserierna samt avgöra om dessa förändringar sker samtidigt i flera serier och i så fall vilka. Baserat på
denna information kommer vi att gå vidare med att utveckla metoder som hjälper oss besvara frågor som till exempel: Hur många
bakomliggande faktorer har vi? Hur ser tidsdynamiken hos de enskilda bakomliggande faktorerna ut? Problemen är komplicerade på så sätt att förändringspunkterna sällan kan bestämmas exakt och vi måste arbeta med sannolikhetsbaserade metoder där vi kommer att behöva ta hänsyn till en mycket stor mängd alternativa händelser. En av utmaningarna består därför i att hålla
beräkningskomplexiteten på en rimlig nivå. Vi hoppas att vi genom att utveckla dessa verktyg kan bidra till förbättrade analysmetoder för tidsserier och på så sätt bidra till utvecklingen inom flera viktiga forskningsfält som till exempel klimatforskning och analys av finansiella tidsserier.

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

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

Keyword 1*

Regime switch model

Keyword 2*

Bayesian

Keyword 3*

change point detection

Keyword 4

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*

Projektet är teoretiskt och metodutvecklande och vi anser inte att etiska frågor är aktuella.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

RESEARCH PROGRAMME

Project Title: Modelling and learning of latent switching processes in change point detection problems.

Purpose and aims

Inferring times of change of behavior in observational data is of utmost importance in many scientific and engineering fields as change of dynamics, or set-points, may lead to necessary interventions. In monitoring of processes and machinery, we need to infer if the dynamics of the process or the operating conditions have changed, thereby indicating a potential fault. In climate and environmental research [1], there is a strong interest to determine if one or more time series show a change in behavior, which could potentially indicate that some critical event has occurred that needs to be addressed.

Econometricians and stock market analysts face similar problems when analysing time series of stock prices or how the economy develops [2]. At some time instant there may be significant changes in the dynamics of the observed time series, and the outcome of currently used decision models for future behavior will be poor unless proper actions to retune or reparameterise these models are taken. In computer networking and cyber-physical systems, change point detection can be used for early detection of intrusions [3]. Attacks on networks typically cause simultaneous data traffic changes in several links of the network and by detecting when such changes occur, measures can be taken to stop or minimise the effects of the attacks.

In wireless sensor network (WSN) applications, changes in the channel variability of different radio links may occur simultaneously as a result of an underlying change in the radio environment. Such changes need to be detected since it may lead to significant changes in the quality of the received data, which will also be reflected in the production performance. Fig. 1 depicts the received signal strengths (RSS) for two nearby WSN-links.[1] Two change points (CPs) are marked, one that is unique to the link presented in the upper diagram (dotted), and one that appears simultaneously in both links (dash-dotted).

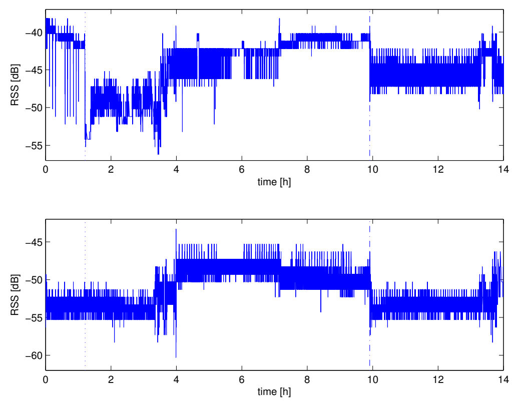

Figure 1: RSS values (in dBm) acquired over time for two WSN-links located 10 meters apart in the same environment. Note the two particular CPs that have been marked. At $t = 1.2$ h (dotted), only the upper series shows a significant change whereas at $t = 9.9$ h (dash-dotted), both series show a simultaneous change, which indicates that they are influenced by a common switching process.

In the above mentioned research fields, it is important to be able to infer whether the dynamics of an underlying process, in the sequel called "switching process" (SP), caused the observed changes in behavior in the time series, or, if it was some other random effect. Such information enables us to build up detailed knowledge about the systems we are observing.

[1] The WSN link data were acquired during a measurement campaign at a rolling mill at Sandvik.

The primary goal of this project is to develop suitable models and methods for describing the dynamics of underlying SPs as discussed above and to estimate the parameters of such processes.

In today's trend towards large data bases [4], frequently consisting of time series of various kinds, making sense of the acquired data is key. This calls for improved methods to understand what are the underlying processes causing changes in the data. We believe that several application fields, in particular those in which controlled experiments are difficult to perform, such as, e.g., environmental research, social sciences, finance etc., would benefit from improved methods for understanding the underlying processes that cause changes in the observed data.

Survey of the Field

The work on CP detection can be divided into two main categories: (i) on-line, or sequential detection and (ii) off-line, or retrospective detection. In (i), the delay between detection of a CP and acting upon it is usually considered to be a critical issue and an important example is fault detection, used, e.g., in process control [5] [6]. Category (i) is not in line with our scope as in (i) the typically aim is to react to something going bad and there is little interest in understanding the underlying mechanisms.

Examples from category (ii) can be found in many fields, such as, e.g., environmental research [7] and finance [8]. Here the task is often to analyse large data sets and draw conclusions from these. Although time may be important, taking immediate action on the same time scale as the changes occur is usually not the key objective. The current proposal falls into this category and we shall here focus on works performed in this area, in which the focus has been on detecting multiple CPs, (MCPs).

To simplify the discussion below we need to introduce some notation that we confine to the single time series case. Let, $Y \triangleq Y_{1:T} = (y(1), ..., y(T))$ denote a discrete time series from time 1 to T.[2] A general assumption in MCP detection is that the statistical behavior of the time series Y is abruptly changed at a set of discrete time CPs, $\mathcal{T} = \{\tau_1 < ... < \tau_{K-1}\}$, where the τ-values and K, usually assumed unknown, are integers. Let us further define $\tau_0 = 1$ and $\tau_K = T$. Y can thus be segmented into K non-overlapping segments, $Y^1, ..., Y^K$, where $Y^k = Y_{\tau_{k-1}:\tau_k - 1}$ is the k:th segment.

The waiting times (in samples) between CPs can be modelled using a probability distribution. Let $g(m|\phi)$ denote such a waiting time distribution for the underlying SP, i.e.,

$$g(m|\phi) = Pr(\tau_{k+1} - \tau_k = m|\phi), \quad m \in \mathbb{N}_1. \tag{1}$$

with ϕ representing the parameters of the waiting time distribution.

Furthermore, the data within the k:th segment, Y^k, are assumed to belong to the same generative process, characterised by some distribution that is parametrized by a vector θ_k, which can either be assumed to be known, or more generally, unknown with prior distribution $p(\theta_k)$. In addition, it is common to assume the segments to be conditionally independent, which in the case of unknown θ_k means that the posterior for $\mathcal{T}$ is proportional to[3]

$$Pr(\mathcal{T}|Y, \phi) \propto \prod_{k=1}^{K} p(Y^k|\mathcal{T})p(\mathcal{T}|\phi) = \prod_{k=1}^{K} p(Y^k|\tau_{k-1}, \tau_k)p(\mathcal{T}|\phi), \tag{2}$$

[2] We use the colon notation as in Matlab to define sequences.

[3] We may expect to find ϕ after the conditioning sign in $p(Y^k|\mathcal{T})$. The reason we can remove ϕ is that conditioning on $\mathcal{T}$ overrides any information about the segment length that would be present in ϕ.

where $p(Y^k|\tau_{k-1}, \tau_k) = \int_{\theta_k} p(Y^k|\tau_{k-1}, \tau_k, \theta_k)p(\theta_k)d\theta_k$ is the marginal likelihood of segment Y^k and $p(\mathcal{T}|\phi)$ is the prior for $\mathcal{T}$, which under the commonly used assumption of independent segments can be expressed as[4]

$$p(\mathcal{T}|\phi) = \prod_{k=1}^{K} g(\tau_k - \tau_{k-1}|\phi) \ . \tag{3}$$

Essentially any family of distributions can be used for modelling the generation of data segments but focus has for obvious reasons been on the use of those that allow for a simple mathematical treatment. Popular choices are those from the exponential family that allow for conjugate priors for the parameters.

In MCP detection, the problem is typically defined as finding the set, $\mathcal{T}$, that maximises $p(\mathcal{T}|Y, \phi)$. The process of finding these CPs, which governs the partitioning of the time series into data sets Y^k, is often called *segmentation* in the literature.

For a sequence of length of T samples, the number of possible segmentations is of the order $O(2^T)$ and a full search in a space of that size is usually unfeasible. One commonly used simplistic methods is the binary segmentation due to Scott [9]. It can be used together with any single CP detection method and the extension to multiple CPs is done by applying it iteratively on subsets of the sequence, making a binary split at each iteration. The advantage is that the search is fast, $O(T \log T)$, and the disadvantage is that there is not guarantee to find the global optimum. Hence, the method risks resulting in segmentations that are of poor quality and provide little or no understanding of the underlying mechanism that is generating the data.

A more accurate approach, guaranteeing that the global maximum of $p(\mathcal{T}|Y, \phi)$ is found, is to use dynamic programming (DP) techniques [10], [11]. The computational cost is then $O(T^2)$. The drawback of the DP approach is that it provides only one single maximum a posteriori (MAP) solution.

A more elaborate approach is to consider the full posterior distribution but since this involves a tabulation of $O(2^T)$ probabilities this is clearly unfeasible for most realistic T. Instead, we must focus on techniques that in some way keep track of a subset of $\mathcal{T}$ consisting of the candidates that have the highest probabilities. We could in principle keep those top candidates in a list and compute their posterior probabilities, but a much more common and practical approach is to use techniques that allows us to draw samples from the posterior distribution $p(\mathcal{T}|Y, \phi)$. These samples can then be subsequently used to extract interesting summary statistics, or shorter, *summaries*. Examples of such statistics can be the posterior probability that we have a CP at a certain time instant, $Pr(t \text{ is a CP}|Y)$, or the probability distribution of the lengths of the segments, $Pr(\tau_k - \tau_{k-1} = m|Y)$. These summaries are generally obtained from the posterior samples in a very simple fashion by counting the number of drawn samples in which the "event" occur, e.g., that t belongs the drawn $\mathcal{T}$, and divide by the number of samples totally drawn from the distribution.

The above described, more fully Bayesian approach, is found in a number of papers including, e.g., [12], [13], [14], [15]. In these papers, samples were drawn from the posterior $p(\mathcal{T}|Y, \phi)$ using Markov Chain Monte Carlo (MCMC) techniques such as the Gibbs sampler or reversible jump MCMC (RJMCMC). Drawbacks with MCMC methods are that it is difficult

[4]Please note that we have simplified the expressions to avoid a cluttered presentation. A more detailed analysis requires special treatment of the first and last segments since the observation sequence may start and end in between two CPs.

to judge when the algorithm has reached stationarity, the so-called burn-in time that allow us to begin drawing representative samples from the posterior distribution, and that the samples are dependent (often called poor "mixing" in the Markov Chain part of MCMC). Analysing the number of iterations required to obtain nearly independent samples in the Markov Chain has turned out to be very difficult. The theoretical studies that have been performed, see, e.g., [16,17], indicate that the number of samples obtained from a MCMC algorithms to yield a results of some pre-specified level of accuracy is polynomial in d, i.e., $O(d^r)$, where d is the dimension of the parameter space we wish to explore and with the exponent, r, ranging between 8 and 19.[5]

Fearnhead [18], based on work by Barry and Hartigan on product partition models [19] and Yao on so-called direct simulation [20], provided an elegant solution to the problem associated with poor mixing in the Markov chain. Instead of brute force MCMC, Fearnhead proposed a two-step algorithm, where in the first step, an auxiliary variable,

$$Q(s) = P(Y_{s:T}|\text{change point at } s-1, \phi), \tag{4}$$

is computed recursively, which can be used in the second step for drawing samples from $p(\mathcal{T}|Y, \phi)$. However, in contrast to MCMC methods, these samples are independent and, thus, the convergence rate for the summaries mentioned above, is significantly improved. The recursions presented in the original work can be completed in time proportional to $O(T^2)$ but later work presented in [21] introduced a pruning mechanism in the algorithm, attaining a computational complexity of $O(T)$ without sacrificing accuracy. The cost of drawing N independent samples is $O(TN)$ and the overall cost is thus quite predictable and will typically be significantly lower than for MCMC methods.

Fearnhead's work dealt with the analysis of a single time series. In [22] and [23], the work was extended to multivariate sequences that were assumed to switch between processes having different covariance structures. Note however that, in contrast to what is proposed here, only a single common underlying switching process was considered.

The models of the waiting times of the SPs, see (1), used in the above references are generally simple. The problem of estimating ϕ parameterizing $g(m|\phi)$, has seldom been considered. Exceptions are found in, e.g., [18] where $g(m|\phi)$ was modelled using a negative binomial distribution and the parameter in this distribution was estimated by embedding the direct sampling method into an MCMC scheme.

In summary, work on parameter estimation of SPs in the context of CP detection problems has been performed earlier but, to the best of our knowledge, there has not been any research on appropriate structures and parametrisations of the SPs. One plausible reason for this is that most work has concerned detection of CPs in single time series only. In such a case, there is realistically very little to gain by modelling the SP as a collection of processes acting in parallel. However, by considering multiple time series, we may observe differences between SPs, which will help revealing the underlying structure. We will discuss this in more detail next.

Project description

We shall in this project develop and analyse algorithms for inferring the dynamics of the underlying SPs governing time series appearing in change point detection problems. In particu-

[5]The study concerned a special case of estimation the volume of a convex set in a d-dimensional space [16] using a simplistic Markov Chain that made an analysis possible. The result $r = 19$ was considered to be overly pessimistic and it was conjectured in [16] that $r = 8$ is a better bound for the same problem, still indicating the inherent difficulties associated with random searches in high dimensions.

lar, we aim at developing methods that use multiple time series that will assist us in solving the following tasks: (i) Detection of MCPs from sets of alternative SPs of which some influence more than one time series, (ii) estimating parameters in several underlying SPs, and (iii) inferring how many SPs that are involved and the distributional form of the waiting times. These problems are all inference problems but on different levels. Tasks (i) and (ii) are examples of *state-* and *parameter estimation*, respectively, whereas (iii) falls into the more difficult category of *structural inference*. Generally, in problems that deal with a combination of such low level and high level inference problems, the subproblems in (i) and (ii) are necessary components that must be solved before we can solve problems of the kind (iii).

It should be noted that all three tasks can be be attacked using MCMC techniques, such as, Gibbs sampling for solving problems in (i) and (ii) and RJMCMC [12] for treating problems in (iii). However, because of their often slow convergence rate, we will primarily focus on the development of alternative methods inspired by the work in [18]. MCMC can, however, provide us with a "golden standard", in the sense that it should yield samples from the correct distributions provided we wait long enough. We will therefore benchmark the accuracy convergence of our alternative methods against MCMC methods.

Before going into detail about how to approach the tasks (i)-(iii) above, let us first discuss some key issues that we believe are necessary to pursue for solving them. The basic idea is that multiple time series contain much more qualified information than a single time series does. A single time series can, of course, be influenced by several SPs, each giving rise to several CPs over time. Unless we impose some strong assumptions about properties of those processes, such as, e.g., periodicity, it is in general difficult to draw conclusions about the properties of the processes based on only one time series. As an example, suppose that we have a set of processes, all producing "spikes" in a fairly periodic fashion but with independent periodicities. A presentation of these spikes on a single time axis,[6] without giving any indication of which process caused which spike, will typically appear as a single process that has fairly random waiting times, i.e., corresponding to a distribution, $g(m|\phi)$, that is fairly uniformly distributed.

In this particular situation we may potentially solve the problem by, in our generative model, allow for several underlying processes, SP_1, SP_2, etc., and setting up separate priors $g_1(m|\phi_1)$, $g_2(m|\phi_2)$, etc., that favour periodic processes. With such a modelling approach we might be able to infer the "identity" of each spike. This approach is however dissatisfactory in the sense that we most probably will need to use very informative priors (in this case strongly favoring periodicity) and this is intimately related to the fact that we are using too little data to answer too complicated questions. It is better if the data provides us with more qualified information.

The situation is indeed more favorable when we consider multiple time series. The perhaps simplest possible version of such a scenario is illustrated in Figure 2 where two time series, X and Y, are influenced by three SPs, SP_x, SP_y, and SP_{xy}, where SP_x and SP_y independently influence CPs, τ^x and τ^y, solely in time series X and Y, respectively, whereas SP_{xy} influences common switch points, τ^{xy}. Let $g_x(m)$, $g_y(m)$, and $g_{xy}(m)$ denote the waiting time distributions of these SP:s. These distributions can be parameterised, independently, in any way we choose with parameter vectors ϕ_x, ϕ_x, and ϕ_{xy}, respectively.

By having two time series and including an additional explanatory SP, SP_{xy}, we are in a

[6] Assume for simplicity that our observed time series has allowed us to determine the CPs with a great certainty. We are "sure" about these and the remaining problem is to sort out what the underlying dynamics of the SPs look like.

better position to distinguish[7] between events that are caused by SP_x, since they appear in X only, events caused by SP_y since they appears in Y only, and events caused by SP_{xy} since they must appear in both X and Y simultaneously. Even though we cannot rule out that some simultaneous event in X and Y is the result of both SP_x and SP_y triggering at the same time, the explanation that SP_{xy} is causing the event will typically be the more probable one. This holds in particular when there are more simultaneous CPs observed than would be expected by pure chance.

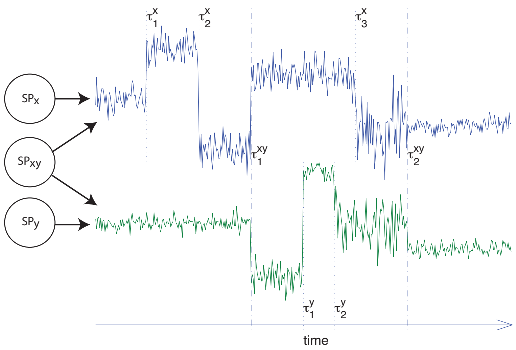

Figure 2: Illustration of a scenario where we have two time series, X (upper) and Y (lower), and three SPs. SP_x and SP_y influence CPs solely in time series X and Y , denoted by τ^x and τ^y respectively, whereas SP_{xy} influences common CPs denoted by τ^{xy}.

If we assume, for the sake of argument, that all simultaneous occurrences are due to SP_{xy} we can proceed to sort out which process caused which CP by removing the common CPs from the CPs observed in X and Y. This can hardly be done if we consider only one time series at a time, and the above discussion makes it reasonable to believe that consideration of multiple time series is the key to solving the tasks (i)-(iii). We proceed below with a more detailed description on these tasks.

Task (i): Detection of multiple CPs from sets of alternative SPs

Based on the model illustrated in Figure 2, we will, as a first step, develop methods for computing posterior probabilities such as $Pr(\text{Common CP at } \tau|X, Y)$, $Pr(\text{CP in only } X \text{at } \tau|X, Y)$, and $Pr(\text{CP in only } Y \text{at } \tau|X, Y)$. We have already begun work on developing algorithms for computing these probabilities using techniques that are similar to those developed by Fearnhead but with the analysis generalised to two sequences. See "Preliminary Results" below.

The problem formulation that we have set up results in recursions that in its basic form have computational complexity $O(T^4)$ when run fully off-line and this poor scaling to T limits its practical use for solving problems that involve long sequences. However, by adopting a pruning technique similar to the one described in [21], it should be possible to reduce the complexity to $O(T)$, without compromising accuracy. In this task we intend develop such pruning techniques suitable for the case with multiple time series.

We will also extend the work to an arbitrary number of time series in the CP detection algorithms. This will be feasible for the following reason: Suppose that we have a set of time series $\{X, Y, Z, ...\}$ and a set of SPs, $\{SP_1, ..., SP_M\}$. Let us assume that each member in the latter set will cause CPs only in some subset of the former set. Let us say, for instance, that SP_1 influences only the subset $\{X, Y\}$, SP_2 influences the subset $\{Y, Z\}$, etc. Then we can view these subsets as indicators that identify the underlying SP. With such indicators we are back to the favorable situation of being able to sort out which CP belongs to which SP and this will help in solving tasks (ii) and (iii) .

It is also quite likely that we can extend the work on developing recursions to compute

[7] Distinguish in a probabilistic sense, i.e., telling which alternative is more probable.

auxiliary variables of similar types as in equations (4) and (5) for three or more time series. However, the complexity of the algorithm will grow quickly with the number of time series, which will be a potential hurdle. Since this area is largely unexplored, we will investigate possible ways to circumvent these hurdles.

Task (ii): Estimating parameters in the underlying SPs

This task will deal with the estimation of parameters $\phi = \{\phi_x, \phi_y, \phi_{xy}\}$ for the respective waiting time distributions, $g_x(m)$, $g_y(m)$, and $g_{xy}(m)$. In the more ambitious version of treating more time series than two, we must, of course, extend the set of distributions.

As already pointed out by Fearnhead, we can attack this problem by embedding the direct sampling of $\mathcal{T}$ into an MCMC framework of lower dimension involving only the ϕ-parameters. This allows for sampling of the joint distribution $p(\mathcal{T}, \phi|Y)$ and we intend to examine this possibility. More importantly, we also intend to consider using some version of the EM algorithm for performing maximum likelihood estimation. EM is a general algorithm that can be used whenever we wish to estimate parameters in models that involve latent variable, which in our case are the unknown CPs, and we intend to examine how we best can fit our problem into the EM framework in order to obtain a computationally efficient algorithm that yields accurate estimates.

Task (iii): Inferring the number of SPs that are involved and their distributional form

This task aims at finding the number of SPs that most likely have caused the different switching events, as well as finding suitable parametric models for the different $g(m|\phi)$ involved. This is a typical model structural inference problem in which we consider a set of competing model structures $M_1, ..., M_L$, all belonging to some set $\mathcal{M}$. For the scenario described in task (i), two models in this set may differ regarding what parametric form we have chosen for $g_x(m|\phi_x)$, $g_y(m|\phi_y)$ and $g_{xy}(m|\phi_{xy})$ and/or the presence of $g_{xy}(m|\phi_{xy})$. Our task is to compute the posterior probabilities $Pr(M_i|X, Y)$ for all $M_i \in \mathcal{M}$. Alternatively, we may choose to search only for the single most likely M_i.

The computation of these probabilities involves integration over a parameter space, ϕ, and for this type of complicated models, involving many latent variables, this may be a formidable task and we do not expect to be able to perform these integrations analytically although we intend to explore the possibilities finding (semi-)analytical results that supports the full solution. There are several methods proposed in the literature for solving this class of problems. One alternative is to use RJMCMC [12], that solves the problem by sampling from a posterior distribution over all model structures, structural EM [24] that iteratively searches the model structure space for the model that maximises the posterior probability, variational methods [25] that use an approximation of the posterior for the parameters ϕ, that can be written in factored form, which immensely simplifies the computation of the above mentioned integral.

We will systematically implement versions of the above mentioned alternatives for structural inference, with focus on those that we expect to be computationally most efficient, such as adopting the structural EM and the variational methods for our problem. The results from these algorithms will be benchmarked with the results from RJMCMC to find out which method has the best structure detection performance.

Preliminary Results

We have recently addressed a problem that is more general than the MCP detection problem. The model used in our approach is illustrated in Fig. 2, with the main novelty being that we analyse a pair of time series, X and Y, and consider three explanatory models for creating the

CP time instants. Two of the considered SPs, SP_x, and SP_y act solely on the time series X and Y, respectively, whereas the third, SP_{xy}, causes a change in both X and Y simultaneously. See also the discussion around Fig. 2.

By using a similar approach as that in [18], forming an auxiliary variable,

$$Q(s,u) = P(X_{s:T}, Y_{t:T}|\text{CPs in X at } s-1 \text{ and in Y at } t-1), \tag{5}$$

that is reminiscent to $Q(s)$ found in equation (4), and developing recursions [26] for computing it, we can draw samples from the joint posterior distribution $p(\mathcal{T}_x, \mathcal{T}_x, \mathcal{T}_{xy}|X, Y)$ and by means of Monte Carlo simulations, we can compute posterior probabilities of events, such as $Pr(\text{Common CP at } t = \tau|X, Y)$, $Pr(\text{CP in only } X \text{at } t = \tau|X, Y)$, and $Pr(\text{CP in only } Y \text{at } t = \tau|X, Y)$. We obtain, in the end, a recursive algorithm that can be completed in $O(T^4)$ operations but with the potential to be made significantly more efficient by using pruning techniques similar to those described in [21].

Time line and project organization

As mentioned earlier, the inference tasks detailed in (i)-(iii) cannot typically be separated from each other. The low level problems are usually necessary components when solving the higher level problems. The outcome from (iii) will depend heavily on the result from (i) and (ii). With this in mind, the safest and probably the most efficient way forward, would be to set up a simplified problem for which we believe we should be able to solve all involved tasks as quickly as possible. In this way we can systematically increase the complexity of our models, evaluate the results and choose suitable solution methods, as indicated above, accordingly. We therefore will adopt the following time line:

- First year: Finalize and test the algorithm discussed in the "Preliminary Results" section. In particular, introduce pruning mechanisms to reduce computational complexity. We will set up a simple and well studied test case, such as two series described by piecewise constant levels in Gaussian noise, with SPs occurring independently in X and Y, or a combination of this and a common process. The ideas suggested in Task (i) and Task (ii) will be tested on this case and we will compare with results obtained with MCMC techniques. From this comparison we can draw conclusions about detection and estimation accuracy and obtain valuable insights of what are the fundamental difficulties in our approach. Real data sets will be considered and we will also start researching the possibilities to extend the recursive methods mentioned in the "Preliminary Results" section to more than two sequences.

- Second year: We will begin the work on developing and implementing structural EM, variational methods, and RJMCMC techniques for solving Task (iii). If the work on recursive methods for more than two time series seems promising, we will also continue with that work.

- Third and fourth year: We will step up the complexity of the test case to become more realistic. In particular, we will here extend the test case to involve a larger number of SPs as well as real world time series and we will examine how our methods scale in terms of computational burden and how estimation accuracy is affected by the upscaling.

The project will be led by A/Prof Olofsson (TO) who will be engaged in all parts of the project at various levels from hands on research to supervision together with Prof Ahlén (AA). During 2016 we will enroll a PhD student (NN) to work primarily on Task (i). The rest of the project is organised according to Table 1.

Table 1: Sub-projects, and active people each year: A/Prof Tomas Olofsson (TO), Prof Anders Ahlén (AA), PhD student (NN), Supervision of NN by TO/AA (SV,NN).

Task	2016	2017	2018	2019
(i)	TO,AA,NN,	SV,NN	SV,NN	SV,NN
(ii)	TO,AA,NN	SV,NN	SV,NN	SV,NN
(iii)	-	AA,TO	SV,NN	SV,NN

Significance

Time series that show abrupt changes appear in various research fields and finding out the causes of these changes is often one of the main research goals since this provides understanding of the processes involved. The project involves development of general tools that will be of use in any of the previously mentioned fields. In particular, we expect that succeeding in development of accurate methods for inferring the dynamics of underlying SPs will help researchers and data analysts to direct their search for the underlying causes of the change in behavior in the sense that they will have better means to efficiently form new hypotheses. Regardless of how big a study of some behavior is, say some time series consisting of environmental data, there is always room for observing yet more data from processes that may influence the already observed processes.

National and International Collaboration

We have a well established collaboration with renowned researchers within the proposed research area and we anticipate this collaboration to continue, and even grow, during the course of this project. In particular, we will collaborate with Prof Daniel E. Quevedo, at University of Paderborn, DE, and Prof Subrakanti Dey at UU, on several topics presented in this project.

Other grants

PI Olofsson has currently no other VR grant. Co-PI Ahlén is the PI of the VR grant "Prediction of radio channels for routing and wireless control", Dnr: 621-2013-5272. There is no overlap between the previous grant and this application.

REFERENCES

[1] O. Seidou and T. Ouarda, "Recursion-based multiple changepoint detection in multiple linear regression and application to river streamflows," *Water Resour. Res.*, vol. 43, no. 7.

[2] "Detecting structural breaks and identifying risk factors in hedge fund returns: A bayesian approach," *Journal of Banking and Finance*, vol. 32, no. 11, pp. 2471 – 2481, 2008.

[3] A. Tartakovsky, B. Rozovskii, R. Blazek, and H. Kim, "A novel approach to detection of intrusions in computer networks via adaptive sequential and batch-sequential change-point detection methods," *Sign. Proc., IEEE Trans. on*, vol. 54, pp. 3372–3382, Sept 2006.

[4] V. Mayer-Schönberger and K. Cukier, *Big data: A revolution that will transform how we live, work, and think*. Houghton Mifflin Harcourt, 2013.

[5] M. Basseville, "Detecting changes in signals and systems – a survey," *Automatica*, vol. 24, no. 3, pp. 309 – 326, 1988.

[6] F. Gustafsson, *Adaptive filtering and change detection*, vol. 1. Wiley New York, 2000.

[7] J. J. Polovina, "Climate variation, regime shifts, and implications for sustainable fisheries," *Bulletin of Marine Science*, vol. 76, no. 2, pp. 233–244, 2005.

[8] C.-J. K. et al, "Estimation of Markov regime-switching regression models with endogenous switching," *Journ. of Econ.*, vol. 143, no. 2, pp. 263 – 273, 2008.

[9] A. Scott and M. Knott, "A cluster analysis method for grouping means in the analysis of variance," *Biometrics*, vol. 30, no. 3, pp. 507–512, 1974.

[10] I. E. Auger and C. E. Lawrence, "Algorithms for the optimal identification of segment neighborhoods," *Bulletin of Mathematical Biology*, vol. 51, no. 1, pp. 39 – 54, 1989.

[11] B. Jackson, J. Scargle, D. Barnes, S. Arabhi, A. Alt, P. Gioumousis, E. Gwin, P. Sangtrakulcharoen, L. Tan, and T. T. Tsai, "An algorithm for optimal partitioning of data on an interval," *Signal Processing Letters, IEEE*, vol. 12, pp. 105–108, Feb 2005.

[12] P. J. Green, "Reversible jump Markov chain Monte Carlo computation and Bayesian model determination," *Biometrika*, vol. 82, no. 4, pp. 711–732, 1995.

[13] B. P. Carlin, A. E. Gelfand, and A. F. M. Smith, "Hierarchical Bayesian analysis of changepoint problems," *Journal of the Royal Statistical Society. Series C (Applied Statistics)*, vol. 41, no. 2, pp. pp. 389–405, 1992.

[14] E. Punskaya, C. Andrieu, A. Doucet, and W. Fitzgerald, "Bayesian curve fitting using MCMC with applications to signal segmentation," *IEEE Trans. Sign. Proc.*, vol. 50, pp. 747–758, Mar 2002.

[15] L. Perreault, J. Bernier, B. Bobée, and E. Parent, "Bayesian change-point analysis in hydrometeorological time series. part 1. the normal model revisited," *Journal of Hydrology*, vol. 235, no. 34, pp. 221 – 241, 2000.

[16] M. Dyer, A. Frieze, and R. Kannan, "A random polynomial-time algorithm for approximating the volume of convex bodies," *Journal of the ACM*, vol. 38, no. 1, pp. 1–17, 1991.

[17] N. Jerrum and A. Sinclair, "The markov chain monte carlo method: an approach to approximate counting and integration," in *Approximation algorithms for NP-hard problems* (D. Hochbaum, ed.), Boston: PWS publishing company, 1997.

[18] P. Fearnhead, "Exact and efficient Bayesian inference for multiple changepoint problems," *Statistics and computing*, vol. 16, no. 2, pp. 203–213, 2006.

[19] D. Barry and J. A. Hartigan, "Product partition models for change point problems," *The Annals of Statistics*, vol. 20, no. 1, pp. pp. 260–279, 1992.

[20] Y.-C. Yao, "Estimation of a noisy discrete-time step function: Bayes and empirical Bayes approaches," *The Annals of Statistics*, vol. 12, no. 4, pp. pp. 1434–1447, 1984.

[21] R. Killick, P. Fearnhead, and I. A. Eckley, "Optimal detection of changepoints with a linear computational cost," *J. Am. Statist. Assoc.*, vol. 107, no. 500, pp. 1590–1598, 2012.

[22] X. Xuan and K. Murphy, "Modeling changing dependency structure in multivariate time series," in *Proc. of the 24th Int. Conf. on Machine Learning*, ICML '07, (New York, NY, USA), pp. 1055–1062, ACM, 2007.

[23] M. Lavielle and G. Teyssière, "Detection of multiple change-points in multivariate time series," *Lithuanian Mathematical Journal*, vol. 46, no. 3, pp. 287–306, 2006.

[24] N. Friedman, "The bayesian structural EM algorithm," in *Proceedings of the Fourteenth Conference on Uncertainty in Artificial Intelligence*, (San Francisco, CA, USA), pp. 129–138, Morgan Kaufmann Publishers Inc., 1998.

[25] M. Jordan, Z. Ghahramani, T. Jaakkola, and L. Saul, "An introduction to variational methods for graphical models," *Machine Learning*, vol. 37, no. 2, pp. 183–233, 1999.

[26] T. Olofsson, *Segmentation using pairwise sequences*, 2014. `http://www.signal.uu.se/Staff/tol/PairwiseSegm.pdf`.

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

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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	Tomas Olofsson	40
2	Participating researcher	Anders Ahle'n	20
3	Other personnel without doctoral degree	PhD student (NN)	80
4	Participating researcher	Anders Ahlén	

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Tomas Olofsson	30	254,000	256,000	259,000	261,000	1,030,000
2	Participating researcher	Anders Ahle'n	0	0	0	0	0	0
3	Other personnel without doctoral degree	PhD student	80	382,000	385,000	389,000	393,000	1,549,000
	Total			636,000	641,000	648,000	654,000	2,579,000

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

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Resor	konferenser/besökare	120,000	120,000	120,000	120,000	480,000
2	Datorer		40,000				40,000
	Total		160,000	120,000	120,000	120,000	520,000

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	636,000	641,000	648,000	654,000	2,579,000		2,579,000
Running costs	160,000	120,000	120,000	120,000	520,000		520,000
Depreciation costs					0		0
Premises					0		0
Subtotal	796,000	761,000	768,000	774,000	3,099,000	0	3,099,000
Indirect costs	239,000	228,000	230,000	232,000	929,000		929,000
Total project cost	1,035,000	989,000	998,000	1,006,000	4,028,000	0	4,028,000

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

Budgeten är baserad på en uppskattning att huvudsökande (TO) och medsökande (AA) kommer att vara ak

Samtliga lönesiffror ovan inkluderar sociala avgifter (lönebikostnader) som 2015 ligger på 48.6%
Vi räknar med att behöva köpa in två datorer men räknar inte med att behöva göra några investeringar i mätu
Resekostnader ska täcka konferenser för TOL , AA och NN och samt bidra till att täcka kostnader för logi f

Uppskattningen av indirekt kostnad är baserat på en prognos på 30%.

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

Tomas Olofsson

CURRICULUM VITAE

Name: **Tomas Olofsson** ***Date of Birth:*** May 2, 1968. ***Citizenship***: Swedish

Higher education qualifications:

1994 Master of Science in Engineering Physics, Uppsala University, Uppsala, Sweden

Doctoral degree:

2000 PhD in Signal Processing, Uppsala University, Uppsala, Sweden. Thesis title: Maximum a posteriori deconvolution of ultrasonic data with applications in nondestructive testing: Multiple transducer and robustness issues. Supervisor: Tadeusz Stepinski

Docent level: December 2012

Current position:

2001- Permanent teaching position as universitetslektor (Assistant Professor, since 2012 Associate Professor) in signal processing at the Dept. of Engineering Sciences, Uppsala University. 50% teaching until 2012. Since 2012, 50% research

Previous positions:

1994-2000 PhD student, Dept. of Technology, Uppsala University.
2007-2008 Project leader part time (50%) at Dirac Research from January 2007 to March 2008.
2010-2012 Part time Senior researcher at Wavetrain in Oslo.

Interuptions in research:

2008 Parental leave between March 2008 and October 2008.
2011 Changed direction of research from ultrasonics to wireless communications. Initially overtaking the responsibility of hardware- and software development of a wireless sensor net-based system for synchronous channel gain measurements at multiple links. This work later paved the way for the work that is now funded in VR-grant *2013-5272: Prediction of radio channels for routing and wireless control.* Overtaking also the responsibility of development of radio channel emulator based on FPGA.

Supervision:

Co-supervisor of Markus Engholm (2009), overtaking main responsibility in the final year during his thesis writing. Co-supervisor of Fredrik Lingvall (2004) whos thesis “Time-domain reconstruction methods for ultrasonic array imaging” was directly based on my thesis work, generalizing it to 2D. Co-supervisor of Erik Wennerström (in practice main supervisor), whos licentiate thesis “Model based reconstruction of ultrasonic images”, (2007) further generalized my thesis work concerning 1D sparse deconvolution methods to 2D. Supervised guest researcher Martin H. Skjelvareid in 2011, introducing him to the field of frequency domain synthetic aperture imaging techniques, which later became the main theme of his 2012 doctoral thesis “Synthetic aperture ultrasound imaging with application to interior pipe inspection”. From the fall 2013 I am the main supervisor of Markus Eriksson.

Master theses:

2000-2015 Examiner and supervisor of more than 30 M.Sc. thesis projects

Pedagogical Activities:

1999- Teaching and course responsibility 50% (on average), mainly on the MSc engineering programs in engineering physic , molecular biotechnology, and bioinformatics. Examples of courses include: Neural networks and pattern recognition, Learning systems for molecular data analysis, Digital signal processing, Signal and systems, Digital technology and computer architechture, Electronics, Transform theory.

2002- Performed three pedagogical projects to improve student's learning in courses in Learning systems, Pattern recognition, and Signal processing.
2003- Founder and responsible of a graduate course on *Bayesian Inference*

Other:

- Experience from collaboration in EC-projects with international research institutes (CEA, Paris; University of Kassel, Universitaet Stuttgart) and industrial partners in nuclear industry (Mitsui Babcock, UK; Tecnatom, Spain; British Energy Limited, UK; AIB-Vinçotte International, Belgium) and airspace industry (EADS, Germany; Dassualt Aviation, France; Airbus Spain; BEA, UK).
- During 2005-2007 and 2013- I have been the course coordinator at the Signals and Systems Group with responsibility for some 15 courses .

Curriculum Vitae for Anders Ahlén

Name:	Anders Ahlén
Current position:	Professor in Signal Processing
Work address and	Signals and Systems, Dept. of Engineering Sciences, Uppsala University,
Telephone:	PO Box 534, SE-75121 Uppsala, Sweden. Tel: +46 18 471 3076
e-mail and url:	Anders.Ahlen@signal.uu.se ; http://www.signal.uu.se/Staff/aa/aa.html

1. Higher education qualification
Lic. Eng. (Teknologie Licentiat), Automatic Control, Uppsala University, 1984.
2. Degree of Doctor
Ph.D. (Teknologie Dr) Automatic Control, Uppsala University, Uppsala Sweden, 1986,
Thesis title: Input Estimation with Appplication to Differentiation. Supervisor: Prof Torsten Söderström.
3. Post Doctoral Positions
December 1990-December 1991; Visiting Research Fellow, Department of Electrical and Computer Engineering, The University of Newcastle, NSW, Australia.
4. Qualification required for appointment as a docent: 1990.
5. Present position
Professor (Chair) of Signal Processing and head of the Signals and Systems Division, Department of Engineering Sciences, 1996-present. Percentage of research varies from year to year, 2012-14 ~50%
6. Previous positions
January 2008-April 2008; Visiting Professor, ARC Center on Complex Dynamic Systems and Control, The University of Newcastle, NSW, Australia.
July 1996-Present; Head of the Signals and Systems Division, Uppsala University
July 1992-June 1996; Associate Professor of Signal Processing, Uppsala University.
July 1990; Associate Professor (Docent) Automatic Control, Uppsala University.
July 1984-June 1989; Assistant Professor, Automatic Control, Uppsala University.
7. Interruptions in research: N/A.
8. Supervision
Post Docs: Piyush Agrawal (April 2012-Feb 2014), Steffi Knorn (Feb. 2014--)
PhD's: 18. Sinchan Biswas, enrolled, March 2014, co-supervisor. 17. Markus Eriksson, enrolled Spetember 2013, co-supervisor. 16. Simon Bertilsson, expected PhD, June 2016, co-supervisor.
15. Rikke Apelfröjd, expected PhD: October 2016, co-supervisor. 14. Annea Barkefors, expected PhD: October 2016, co-supervisor. 13. Adrian Bahne, Multichannel Audio Signal Processing: Room Correction and Sound Perception, October 2014. (Project Manager, Dirac Research AB)
12. Daniel Aronsson, *On channel estimation and prediction for MIMO OFDM systems: Key design and performance of Kalman-based algorithms, March 2011. (MathWorks)*
11. Lars-Johan Brännmark, *Robust Sound Field Control for Audio Reproduction: A Polynomial Approach to Discrete-time Acoustic Modeling and Filter Design,* Feb. 2011.*(Chief Scientist, Dirac Research AB)*
10. Erik Björnemo, *Energy Constrained Wireless Sensor Networks: Communication Principles and Sensing Aspects*, January 2009 (Senior Researcher at Petroleum Geo-Services)
9. Mathias Johansson, *Resource Allocation under Uncertainty - Applications in Mobile Communications*, October 2004 (CEO, Dirac Research AB)
8. Nilo Casimiro Ericsson, *Revenue Maximization in Resource Allocation: Applications in Wireless Communication Networks* October 2004 (Head of Engineereing, (Prev. CEO) of Dirac Research AB)
7. Jonas Öhr, *On Anti-Windup and Control of Systems with Multiple Input Saturations: Tools, Solutions and Case Studies* , August 2003, (ABB Corporate Research, Sweden)
6. Torbjörn Ekman, *Prediction of Mobile Radio Channels: Modeling and Design*, October 2002, (Full Professor at NTNU, Norway)
5. Björn Hammarberg, *A Signal Processing Approach to Practical Neurophysiology. A Search for Improved Methods in Clinical Routine and Reseach*, April 2002, (Safegate International, Sweden)
4. Claes Tidestav, *The Multivariable Decision Feedback Equalizer Multuser Detection and Interference Rejection*, December 1999, (Ericsson Research, Sweden)
3. Erik Lindskog, *Space-Time Processing and Equalization for Wireless Communications*, May 1999, (Beceem Communications, USA)
2. Kenth Öhrn, *Design of Multivariable Cautious Discrete-time Wiener Filters: A Probabilistic Approach*, May 1996, (Bombardier Transportation, Sweden)

1. Lars Lindbom, *A Wiener Filtering Approach to the Design of Tracking Algorithms, with Applications in Mobile Radio Communications*, November 1995, (Ericsson Research)

I have also been the main advisor or co-advisor of 10 licentiate theses. Apart from the theses above I have contributed significantly to several other PhD theses at the Signals and Systems Division. Since I was appointed full professor and head of group, 20 PhD thesis (one of which has been downloaded > 22 000 times) and 18 licentiate theses have been presented. I currently advise/co-advise of 6 PhD students.

9. Additional Information: Networks in academia and industry (selected)

ABB, EU-WINNER project and the EU Network of Excellence NEWCOM, e.g., Ericsson, Nokia, etc. and several universities. In particular I would like to mention Chalmers, Göteborg, Karlstad University, KTH, Stockholm, NTNU Trondheim, The University of Newcastle, Australia, The Australian National University, University of Western Australia, University of Melbourne, North-Eastern University, USA, Politechnico di Milano, and Politechnico di Bari, Aalborg University, University of Seville, Federico Santa María Technical University, University of Paderborn, with whom I have, or have had, active collaboration, and/or for whom I have served as external reviewer of PhD theses, expert for promotions, or have exchanged PhD students. Recently I have also established connections with China, e.g., USTC, BUPT, and Southeast University. With the latter two I have, together with colleagues, had a joint VINNOVA/MOST funded research project. I have also hosted a researcher from Sony Corporation, Japan for a year, and several other researchers/PhD students from Europe, Asia, and Australia.

10. Additional Information: Entrepreneurial achievements

-2010-Present: Member of the Board of Directors, Allgotech AB.
-2010: Co-founder of Allgotech AB.
-2008: Co-founder of WISENET Holding AB.
-May 2005-Present: Chairman of the Board of Directors, Dirac Research AB.
-July 2001-2004: CEO of Dirac Research AB.
-2001: Co-founder of Dirac Research AB. A world leading company licensing state-of-the-art audio signal processing solutions to prestigeous customers such as, e.g., BMW, BMW-M, Bentley, Rolls Royce, Digital Datasat Entertainment, Pioneer, Xiaomi, Oppo, Olympus, Naim, Lear Corp., ASK, Sonic Studio, and Jays.
-Holder of 8 patents

11. Additional Information: Other Merits of relevance (selected)

-2014: Area editor for Signal Processing at the Swedish Research Council (VR)
-2010, 2011, 2012, 2013, 2014, 2015 ; (~8 weeks) Visiting Professor, ARC Center on Complex Dynamic Systems and Control, The University of Newcastle, NSW, Australia.
-2007-2013: Part of the WISENET, Vinnova Excellence Center in Wireless Sensor Networks
-2007-2008: Chairman for the evaluation committee, Signals and Systems, the Swedish Research Council
-2007: Member of the decision committee for the selection of the 20 future research leaders, a 5 year grant awarded to promising young researchers by The Foundation for Strategic Research (SSF), Sweden.
-2005: Vice Chair, technical program committee, Transmission Technology, VTC2005 Spring, Stockholm. (Responsible for the review and organization of 480 papers)
-2004: International expert for the evaluation of the Western Australian Telecom. Research Centre (WATRI) at the University of Western Australia, Perth, Australia.
-2004: Member of the evaluation committee for the Swedish Research Council.
-1998-March 2004; Editor for IEEE Transactions on Communications (Area: Signal and Modulation Design).
-July 1993-June 1999: Member of the board of The Faculty of Science and Tech., UU.
-May 2001, Winner of Business Plan Contest Venture Cup East. The competition consisted of 342 other business ideas from Swedish universities
-1987-present: Principal Investigator/Co-Investigator of some 20 research projects funded by VR, SSF, and VINNOVA and PI of an infrastructure grant from the Knut and Alice Wallenberg Foundation.
-On a regular basis: Reviewer for the top international journals and conferences in signal processing, communications, and control, evaluator of PhD (international and national) and licentiate theses, applications for university positions, research proposals, member of technical committees, chairman at international conferences, and invited talks.

Publication list

List of publications: Tomas Olofsson
Google scholar

Peer-reviewed articles:

1. F. Lingvall and T. Olofsson and T. Stepinski, “Synthetic Aperture Imaging using Sources with Finite Aperture–Deconvolution of the Spatial Impulse Response”, *Journal of the Acoustical Society of America*, vol 114, no. 1, pp. 225–34, July 2003. Number of citations: 60
2. T. Olofsson and T. Stepinski, “Maximum a posteriori deconvolution of sparse ultrasonic signals using genetic optimization”, *Ultrasonics*, vol. 37, no. 6, pp. 423–32, Sept 1999, Number of citations: 28
3. T. Olofsson, ”Semi-sparse Deconvolution Robust to Uncertainties in the Impulse Resonses”, *Ultrasonics*, v 42, no. 9, pp. 969-975, April, 2004. Number of citations: 21
4. F. Lingvall and T. Olofsson, ”On Time-domain Model Based Ultrasonic Array Imaging.”,*IEEE Trans. on Ultrasonics, Ferroelectrics and Frequency Control*, vol. 54, no. 8, pp. 1623-1633, Aug. 2007, Number of citations: 20
5. T. Olofsson, ”Phase shift migration for imaging layered objects and objects immersed in water.”, *IEEE Trans. on Ultrasonics, Ferroelectrics and Frequency Control*, vol 57, no. 11, pp. 2522-2530, Nov. 2010, Number of citations: 18
6. * M. Johansson and T. Olofsson, ”Bayesian Model Selection for Markov, Hidden Markov, and Multinomial Models.”, *IEEE Signal Processing Letters*, vol. 14, no. 2, February 2007, pp 129-132. Number of citations: 13
7. T. Olofsson and E. Wennerström, ”Sparse Deconvolution of B-scan Images.”, *IEEE Trans. on Ultrasonics, Ferroelectronics and Frequency Control*, vol. 54, no. 8, August 2007, pp. 1623-1633. Number of citations: 16
8. F. Lingvall and T. Olofsson, ”Statistically motivated design of input signals for modern ultrasonic array systems”, *Journal of the Acoustical Society of America*, vol. 123, no. 5, pp 2620-2630, 2008. Number of citations: 2
9. M. Hansen Skjelvareid, T. Olofsson, Y. Birkelund and Y. Larsen, ”Synthetic Aperture Focusing of Ultrasonic Data from Multilayered Media Using an Omega-K Algorithm” for *IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control*, vol 58, no. 5, pp. 1037-1048, May 2011. Number of citations: 13
10. M. Engholm, T. Stepinski, and T. Olofsson, ”Imaging and suppression of Lamb modes using adaptive beamforming”, *Smart Mater. Struct.*, Vol 20, no. 8, August 2011. Number of citations: 3
11. * P. Agrawal, A. Ahlén, T. Olofsson, and M. Gidlund, ”Long Term Channel Characterization for Energy Efficient Transmission in Industrial Environments.”, IEEE Transactions on Communications Vol 62, no. 8, 2014. Number of citations: 1
12. * T. Olofsson, A. Ahlén, and M. Gidlund, (2015) “Modeling of Wireless Sensor Network Channels in Industrial Environments.” Characterization for Energy Efficient Transmission in Industrial Environments. ” Under review for IEEE Transactions on Signal Processing. See also http://www.signal.uu.se/Staff/aa/rev-TSP3.pdf

Peer-reviewed Conference articles

1. T. Olofsson and T. Stepinski, "Frequency-domain SAFT for the Ultrasonic Inspection of Coarse Grained Metals", 7th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components, Yokohama, May 12-14, 2009. Number of citations: 0

2. T. Olofsson and T. Stepinski, "Phase shift migration for imaging layered materials and objects immersed in water", presented at 2009 IEEE Int. Ultrasonics Symposium, Rome, Sept. 2009. Number of citations: 0

3. T. Olofsson, M. Hansen Skjelvareid, and A. Barkefors *Ultrasonic Imaging of Immersed Objects using Migration Techniques*, Proceedings of 8th European Conference on Synthetic Aperture Radar, June 2010, Aachen, Aug. pp 442-445. Number of citations: 2

4. M.H. Skjelvareid, Y. Birkelund, T. Olofsson, and Y. Larsen, *Ultrasonic imaging of pitting using multilayer synthetic aperture focusing*, Proceedings of IEEE Ultrasonics Symposium, Orlando 2011, pp. 2042-2045. Number of citations: 1

5. M.H. Skjelvareid, T. Olofsson, Y. Birkelund, *Three-dimensional ultrasonic imaging in multilayered media*, In Proceedings of International Congress on Ultrasonics, Gdansk 2011, pp 169-172. Number of citations: 1

6. *P. Agrawal, A. Ahlén, T. Olofsson, and M. Gidlund (2014) " Characterization of Long Term Channel Variations in IndustrialWireless Sensor Networks." International Conference on Communications (ICC), Sydney, Australia, June 2014. Number of citations: 2

LIST OF PUBLICATIONS, 2007 - 2014

Anders Ahlén, March 2015

Citations by Google Scholar

1. Peer-reviewed original articles

1.1 M. Sternad, T. Svensson, T. Ottosson, A. Ahlén, A. Svensson and A. Brunström (2007)
Towards systems beyond 3G based on adaptive OFDMA transmission.
Processings of the IEEE, vol. 95, no. 12, pp. 2432-2455, December 2007. Number of citations: 117.

1.2 L-J. Brännmark and A. Ahlén (2009)
Spatially Robust Audio Compensation Based on SIMO Feedforward Control.
IEEE Transactions on Signal Processing, no 4, vol. 5, 2009. Number of citations: 16.

1.3 D. E. Quevedo, A. Ahlén, and J. Østergaard (2010)
Energy Efficient State Estimation With Wireless Sensors Through the Use of Predictive Power Control and Coding.
IEEE Transactions on Signal Processing, Vol. 58, No9, pp. 4811-4823, 2010. Number of citations: 44.

1.4 D. E. Quevedo, A. Ahlén, A. S. Leong, and S. Dey (2012)
On Kalman Filtering Over Fading Wireless Channels With Controlled Transmission Powers.
Automatica, Vol 48, no7, pp 1306-1316, July 2012. Number of citations: 40.

1.5 * D. E. Quevedo, A. Ahlén, and K. H. Johansson (2013)
State Estimation Over Sensor Networks With Correlated Wireless Channels.
IEEE Transactions on Automatic Control. Vol. 58, No. 3, pp. 581-593, March 2013. Number of citations: 24.

1.6 L-J. Brännmark, A. Bahne and A. Ahlén (2013)
Compensation of Loudspeaker-Room Responses in a Robust MIMO Control Framework.
IEEE Transactions on Audio, Speech, and Language Processing. Vol. 21, No.6, pp. 1201-1216, June 2013. Number of citations: 8.

1.7 D. E. Quevedo, K. H. Johansson, A. Ahlén, I. Jurado (2013)
Adaptive Controller Placement for Wireless Sensor-Actuator Networks with Erasure Channels,
Automatica. Vol. 49, pp. 3458-3466. Number of citations: 5.

1.8 A. Bahne, L-J. Brännmark, and A. Ahlén (2013)
Pairwise Channel Similarity in Loudspeaker–Room Equalization.
IEEE Transactions on Signal Processing. Vol. 22, No 2, pp. 6276-6290, December 15, 2013. Number of citations: N/A.

1.9 D. E. Quevedo, J. Østergaard, and A. Ahlén (2014)
A Power Control and Coding Formulation for State Estimation with Wireless Sensors,
IEEE Transactions on Control Systems Technology. Vol. 22, No 2, pp. 413-427, March 2014. Number of citations: 6.

1.10 * P. Agrawal, A. Ahlén, T. Olofsson, and M. Gidlund (2014)
Long Term Channel Characterization for Energy Efficient Transmission in Industrial Environments.
IEEE Transactions on Communications, vol 62, no. 8, pp 3004-3014, 2014. Number of citations: N/A.

1.11 M. Nourian, S. Dey, and A. Ahlén (2014)
Distortion Minimization in Multi-Sensor Estimation with Energy Harvesting.
IEEE Journal of Selected Areas in Communications. To Appear. Number of citations: N/A.

1.12 L. J. Brännmark, and, A. Ahlén (2015)
Multichannel Room Correction with Focus Control..
Journal of the Audio Engineering Society, Special Issue on Spatial Audio, vol. 63, no. 1/2, pp. 21-30, January/February 2015. Number of citations: N/A.

1.13 S. Knorn, S. Dey, A. Ahlén, and D. E. Quevedo (2015)
Multi-Sensor Estimation Using Energy Harvesting and Energy Sharing.
IEEE Transactions on Signal Processing, vol x. pp 1-15. To appear.

1.14 A. S. Leong, D. E. Quevedo, A. Ahlén, and K. H. Johansson (2015)
Network Topology Reconfiguration for State Estimation Over Sensor Networks With Correlated Packet Drops.
Under review for *IEEE Transactions on Automatic Control*. See also http://www.signal.uu.se/Staff/aa/rev-TAC.pdf

1.15 A. Bahne, and A. Ahlén (2015)
Personal Multichannel Spatial Audio.
Under review for *IEEE Transactions on Audio Speech and Language Processing*. See also http://www.signal.uu.se/Staff/aa/rev-TSLP2.pdf

1.16 S. Knorn, and A. Ahlén (2015)
Transient Scalability in MultiAgent Systems Described by Undirected Graphs.
Under review for *Automatica*. See also http://www.signal.uu.se/Staff/aa/rev-Automatica1.pdf

1.17 * T. Olofsson, A. Ahlén, and M. Gidlund (2015)
Modeling of Wireless Sensor Network Channels in Industrial Environments.
Under review for *IEEE Transactions on Signal Processing*. See also http://www.signal.uu.se/Staff/aa/rev-TSP3.pdf

2. Peer-reviewed conference contributions)

2.1 E. Björnemo, , M. Johansson and A. Ahlén (2007)
Two hops is one too many in an energy-limited wireless sensor network. *IEEE International Conference on Acoustics, Speech and Signal Processing.*, Honolulu, Hawaii, May 2007. Number of citations: 13.

2.2 M. Johansson, E. Björnemo and A. Ahlén (2007)
Fixed link margins outperform power control in energy-limited wireless sensor networks. *IEEE International Conference on Acoustics, Speech and Signal Processing.*, Honolulu, Hawaii, May 2007. Number of citations: 10.

2.3 E. Björnemo, A. Ahlén and M. Johansson (2007)
On the energy efficiency of cooperative MIMO in Nakagami fading wireless sensor networks . *Asilomar Conferences on Signals, Systems, and Computers.*, Asilomar, California, July 2007. (Invited paper). Number of citations: 6.

2.4 A. Ahlén, B. Ahlgren, R. Grnros, P. Gunningberg, K. Hjort, I. Katardjiev, C. Rohner and A. Rydberg (2008)
Robust loudspeaker equalization based on position-independent excess phase modeling. *Presentation of the VINN Excellence Center for Wireless Sensor Networks (WISENET).*, *Conference on Radio Science (RVK08)*, Växjö, Sweden, June 2008

2.5 L-J. Brännmark, and A. Ahlén (2008)
Robust loudspeaker equalization based on position-independent excess phase modeling. *IEEE International Conference on Acoustics, Speech and Signal Processing.*, Las Vegas, Nevada, April 2008. Number of citations: 4.

2.6 D. E. Quevedo, and A. Ahlén (2008)
A predictive power control scheme for energy efficient state estimation via wireless sensor networks. *IEEE Conference on Decision and Control.*, Cancún, Mexico, December 2008. Number of citations: 11.

2.7 D. E. Quevedo, A. Ahlén, and G. C. Goodwin (2008)
Predictive Power Control of Wireless Sensor Networks for Closed Loop Control. *International Workshop on Assessment and Future Directions of Non-Linear Model Predictive Control*, Pavia, Italy, September 2008. Number of citations: 5.

2.8 J. Østergaard, D. E. Quevedo, and A. Ahlén (2009)
Predictive Power Control and Multiple Description Coding for Wireless Sensor Networks. *IEEE International Conference on Acoustics, Speech and Signal Processing.*, Taipei, Taiwan, April 2009. Number of citations: 2.

2.9 D. E. Quevedo, A. Ahlén, J. Østergaard and G. C. Goodwin (2009)
Innovation based state estimation with wireless sensor networks. *European Control Conference, (ECC'09).*, Budapest, Hungary, August 2009. Number of citations: 1.

2.10 L-J. Brännmark and A. Ahlén (2009)
Variable Control of the Pre-Response Error in Mixed Phase Audio Precompensation.
2009 IEEE Workshop on Applications of Signal Processing to Audio and Acoustics (WASPAA 2009). Oct. 2009 New York City, NY. Number of citations: 1.

2.11 J. Østergaard, D. E. Quevedo, and A. Ahlén (2010)
Predictive Power Control For Dynamic State Estimation Over Wireless Sensor Networks With Relays. *Eusipco 2010*, 23-27 August 2010, Aalborg, Denmark. Number of citations: 3.

2.12 D. E. Quevedo, A. Ahlén, A. S. Leong, and S. Dey (2011)
On Kalman Filtering with Fading Wireless Channels Goverened by Power Control. *18th IFAC World Congress*, Milano, Italy, August 28 - September 2, 2011. Number of citations: 2.

2.13 * D. E. Quevedo, A. Ahlén and K. H. Johansson (2011)
Stability of State Estimation over Sensor Networks with Markovian Fading Channels. *18th IFAC World Congress*, Milano, Italy, August 28 - September 2, 2011. Number of citations: 11.

2.14 O. Eriksson, E. Björnemo, A. Ahlén and M. Gidlund (2011)
On Hybrid ARQ Adaptive Forward Error Correction in Wireless Sensor Networks. *37th Annual Conference of the IEEE Industrial Electronics Society*, Melbourne, Australia, November 7 - November 11, 2011. Number of citations: 3.

2.15 L-J. Brännmark, A. Bahne and A. Ahlén (2012)
Improved Loudspeaker-Room Equalization Using Multiple Loudspeakers and MIMO Feedforward Control. *IEEE International Conference on Acoustics, Speech and Signal Processing, ICASSP 2012*, Kyoto, Japan, March 2012. Number of citations: 2.

2.16 A. Bahne, L-J. Brännmark, and A. Ahlén (2012)
Improved Loudspeaker-Room Equalization for Stereo Systems Regarding Channel Similarity. *IEEE/IET International Conference on Audio, Language and Image Processing, ICALIP2012*, Shanghai, China, July 2012. Number of citations: 1.

2.17 D. E. Quevedo, K. H. Johansson, A. Ahlén and I. Jurado (2012)
Dynamic Controller Allocation for Control over Erasure Channels. *3rd IFAC Workshop on Distributed Estimation and Control in Networked Systems*, Santa Barbara, USA, September 2012. Number of citations:5.

2.18 A. Limmanee, S. Dey, and A. Ahlén (2013)
Distortion Minimization via Multiple Sensors under Energy Harvesting Constraints. *SPAWC 2013*. Number of citations: 1.

2.19 * P. Agrawal, A. Ahlén, T. Olofsson, and M. Gidlund (2014)
Characterization of Long Term Channel Variations in Industrial Wireless Sensor Networks. *International Conference on Communications (ICC), Sydney, Australia, June 2014*.

2.20 A. S. Leong, D. E. Quevedo, A. Ahlén, and K. H. Johansson (2014)
Network Topology Reconfiguration for State Estimation Over Sensor Networks With Correlated Packet Drops. *IFAC World Congress*, Cape Town, South Africa, August 2014

2.21 S. Knorn, S.Dey, A. Ahlén, and D. E. Quevedo (2015)
Multi-Sensor Estimation Using Energy Harvesting and Energy Sharing. *International Conference on Communications (ICC), London, UK, June 2015*.

4. Books and book chapters

4.1 D. E. Quevedo, A. Ahlén, and G. C. Goodwin (2009)
Predictive Power Control of Wireless Sensor Networks for Closed Loop Control. *In Springer Series; Lecture Notes in Control and Information Sciences*, Springer.

4.2 I. Jurado, D. E. Quevedo, K. H. Johansson, and A. Ahlén (2013)
Cooperative Dynamic MPC for NCSs. *in Distributed MPC Made Easy*, Berlin Heidelberg: Springer-Verlag.

5. Patents

5.1 M. Sternad and A. Ahlén (2004)
Swedish Patent 0201145-0 Digital audiokompensering (Audio precompensation system).

5.2 M. Sternad and A. Ahlén (2006)
European Patent 1355509 Digital Audio Precompensation.

5.3 M. Sternad and A. Ahlén (2007)
U.S. Patent 7,215,787 B2 Digital Audio Precompensation.

5.4 L-J. Brännmark, M. Sternad and A. Ahlén (2009)
European Patent 08102812-8 Spatially Robust Audio Compensation.

5.5 M. Sternad and A. Ahlén (2009)
Chinese Patent 03110446.0, Method and System for Designing a Digital Audio Precompensation Filter.

5.6 L. J. Brännmark, M. Sternad and A. Ahlén (2009) European Patent 08102812-8 Spatially Robust Audio Compensation

5.7 P-A. Fritjofsson and A. Ahlén (2011)
Swedish Patent SE 534194C2, Pressurization Device for Hose.

5.8 L-J. Brännmark, M. Sternad and A. Ahlén (2012)
U. S. Patent 8194885, Spatially Robust Audio Compensation.

5.9 L-J. Brännmark, A. Ahlén, and A. Bahne (2012)
Audio Precompensation Controller Design Using a Variable Set of Support Loudspeakers. International PCT Patent Application.

5.10 A. Bahne, L. J. Brännmark, and A. Ahlén (2013)
Audio Precompensation Controller Design With Pairwise Loudspeaker Channel Similarity. International PCT Patent Application.

5.11 A. Bahne, and A. Ahlén (2014)
Personal Multichannel Audio Controller Design. International PCT Patent Application.

8. Five most cited journal papers

8.1 M. Sternad T. Svensson, T. Ottosson, A. Ahlén, A. Svensson and A. Brunström (2007)
Towards systems beyond 3G based on adaptive OFDMA transmission.
Processings of the IEEE, vol. 95, no. 12, pp. 2432-2455, December 2007. Number of citations: 117.

8.2 A. Ahlén and Sternad M. (1991)
Wiener filter design using polynomial equations. *IEEE Transactions on Signal Processing*, vol SP-39, pp 2387–2399. Number of citations: 95.

8.3 L. Lindbom, M. Sternad and A. Ahlén (2001)
Tracking of time-varying mobile radio channels. Part I: The Wiener LMS algorithm.
IEEE Transactions on Communications, vol. 49, pp. 2207-2217, December. Number of citations: 91.

8.4 S. Graebe and A. Ahlén (1996)
Dynamic transfer among alternative controllers and its relation to antiwindup controller design. *IEEE Transactions on Control Systems Technology*, vol 4, pp 92-99, January 1996. Number of citations: 82.

8.5 L. Lindbom, A. Ahlén M. Sternad and M. Falkenström (2002)
Tracking of time-varying mobile radio channels. Part II: A case study on D-AMPS 1900 channels.
IEEE Transactions on Communications, vol. 50, pp. 156-167, January. Number of citations: 77.

9. Five most cited conference papers

9.1 M. Sternad, T. Ottosson, A. Ahlén and A. Svensson (2003)
Attaining both coverage and high spectral efficiency with adaptive OFDM downlinks. *IEEE Vehicular Technology Conference VTC 2003-Fall*, Orlando, Florida, Oct. 2003. Number of citations: 174.

9.2 W. Wang, T. Ottosson, M. Sternad, A. Ahlén and A. Svensson (2003)
Impact of multiuser diversity and channel variability on adaptive OFDM.
IEEE Vehicular Technology Conference VTC 2003-Fall, Orlando, Florida, Oct. 2003. Number of citations: 101.

9.3 M. Sternad, T. Ekman and A. Ahlén (2001)
Power prediction on broadband channels.
IEEE Vehicular Technology Conference VTC2001-spring, Rhodes, Greece, May 6-9 2001.
Number of citations: 47.

9.4 T. Ekman, M. Sternad, and A. Ahlén (2001)
Unbiased power prediction of Rayleigh fading channels.
IEEE Vehicular Technology Conference VTC2002-fall, September 24-28, 2002. Number of citations: 46.

9.5 N. C. Ericsson, A. Ahlén, S. Falahati, and A. Svensson **Hybrid type-II ARQ/AMS supported by channel predictive scheduling in a multi-user scenario.** *IEEE Vehicular Technology Conference, Fall 2000 (VTC2000)*, Boston, MA, USA, September 24-28, 2000, pp 1804-1811. Number of citations: 23.

CV

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Dissertation title (swe)

Dissertation title (en)

Maximum a posteriori deconvolution of ultrasonic data with applications in nondestructive testing.

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Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20205. Signalbehandling	ISBN 91-506-1440-1	2000-12-01

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Input Estimation with Application to Differentiation

Dissertation title (en)
Input Estimation With Application to Differentiation

Organisation	Unit	Supervisor
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Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20202. Reglerteknik	ISBN 91-554-1850-3	1986-05-16

Publications

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Publications

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Ahlén, Anders 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:

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- the institution approves the cost-estimate in the application
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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.

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