Vetenskapsrådet

Application

2015-03-31

2015-03972	**Sjöberg, Jonas**	**NT-14**

Information about applicant

Name: Jonas Sjöberg

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Administrating organisation: Chalmers tekniska högskola

Project site: Inst för Signaler och system

Information about application

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

Type of grant: Projektbidrag

Focus: Fri

Subject area:

Project title (english): Identification of nonlinear block-models

Project start: 2016-01-01

Project end: 2019-12-31

Review panel applied for: NT-14

Classification code: 20202. Reglerteknik, 20205. Signalbehandling

Keywords: Wiener–Hammerstein, System identification, Block-oriented models, series expansion

Funds applied for

Year:	2016	2017	2018	2019
Amount:	961	973	1,025	1,058

Descriptive data

Project info

Project title (Swedish)*

Identifiering av olinjära blockmodeller

Project title (English)*

Identification of nonlinear block-models

Abstract (English)*

This proposal concerns the situation where a block based nonlinear models are to be identified, and there is more than one block containing linear dynamics, such as the Wiener-Hammerstein model. Then, the problem is to obtain a good initial parameter estimate using a preliminary linear model of the system describing the entire dynamics. More specific, the project concerns how the poles and zeros of the preliminary model should be divided between the linear blocks. This will be done by describing the division between the blocks with continuous parameters which can be identified using data.

By describing the division of the poles and zeros with continuous parameters gives fractional poles and zeros. This is handled by Tailor expanding the estimates so that they become FIR models. In fact, the whole Wiener-Hammerstein model can be described as a linear regression problem and this is very tractable due to the nice properties of LS problems. There are however, many unclear issues which need to be investigated. Among other things can the LS problem become very large, so large that it becomes a problem even for LS problems. Except that, there are user parameters which need to be investigated how they should be set. Statistical properties are also of interest and will be investigated.

Popular scientific description (Swedish)*

Matematiska modeller används i stort sett överallt och detta projekt handlar om teknik för att ta fram sådana modeller utifrån mätta data. Tex används matematiska modeller i de flesta maskiner där något rör på sig. Genom att ha en modell för det som ska förflyttas så kan datorn som styr maskinen lägga på rätt spänningsnivå så att rörelsen blir som avsett. En mer exakt modell ger då också en mer exakt rörelse. I många fall där något ska styras så ändras egenskaperna, tex med förslitning, eller beroende på temperatur. Då kan det vara intressant att kunna förbättra styrningen genom att anpassa modellen till förändringarna. Beroende på vad det handlar om för maskin så kan sådan funktionalitet ge stora energibesparingar, eller göra en process mer miljövänlig, eller så kan man tillverka med högre kvalitet.

Det här projektet handlar om att utveckla ny algoritmer för att skatta olinjära modeller med hjälp av data från den process, eller maskin, som man är intresserad av. Mer specifikt så handlar det om modeller där dynamiken är linjär men uppdelad på olika ställen med olinjära element där emellan. Utgångspunkten är att man har en rätt bra linjär modell som beskriver den totala dynamiken, och projektet handlar om att ta fram metoder hur den linjära dynamiken ska delas upp till de olika delarna i den olinjära modellen. Om man kan göra detta bra så är det sedan oftast inget större problem att skatta de olinjära delarna. Angreppssättet är att man ska initialt sätta all dynamik på båda ställena och sedan skattar man med hjälp av data i vilket av blocken som dynamiken passar bäst enligt de mätdata man har från processen.

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 > 20202. Reglerteknik 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*

Wiener–Hammerstein

Keyword 2*

System identification

Keyword 3*

Block-oriented models

Keyword 4

series expansion

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*

Inga etiska aspekter i projektet.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

Identification of nonlinear block models

Models are used almost everywhere, and during the last decades, a significant part of the research progress has been made on model based methods, eg, in both signal processing and control design theory. Typically, these methods give optimal performance, according to some definition, assuming that the system considered is accurately described by a mathematical model. Hence, the model quality is essential for these types of algorithms, and methods to obtain reliable high quality models is therefore of high importance.

This project proposal concerns investigation and development of new algorithms for nonlinear system identification, eg, algorithms for estimating nonlinear models using measured data from the process to be modeled. The focus is on a specific class of models which can be described with blocks containing either linear dynamics or static nonlinearities.

1 Purpose and aims

The purpose with the project is to develop

- algorithms for identification of block oriented models,
- especially the initialization of the linear blocks is concerned and how a linear model containing all the dynamics can be divided so that each linear block receives the correct poles and zeros,
- and to investigate the properties of the algorithms and the models estimated thereof.

The starting point is a linear model (BLA - Best Linear Approximation), and to obtain a good initialization of the nonlinear block model, the poles and zeros must be divided between the linear blocks (assuming that they are more than one). The proposal describes an approach where the division of the poles and zeros is relaxed and described by real parameters which then are identified using data from the system.

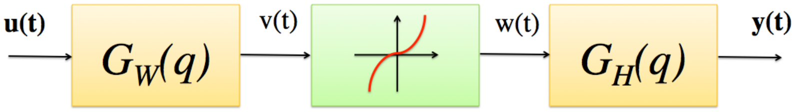

Figure 1: A Wiener-Hammerstein model structure.

The aim is to obtain better, faster and more reliable estimation algorithms for the targeted model structures.

2 Survey of the field

We are concidering models built up by combining blocks which are either linear dynamic or static nonlinear. By constraining the dynamics to be linear one can use part of the linear system theory which makes analysis of the model properties become easier. The simplest block-oriented models are the Hammerstein model and the Wiener model where the Hammerstein model consists of a static nonlinearity followed by a linear dynamic block. The Wiener model has the two blocks in the reversed order. These models can be generalized into Hammerstein-Wiener models, which has two static nonlinear blocks with a linear dynamic block in between, and Wiener-Hammerstein models with two linear blocks with a static nonlinear block in the middle, see Figure 1.

General in system identification, the prediction error estimate gives an asymptotic efficient estimator when the number of estimation data goes to infinity, see, eg, [9, 14]. However, in most cases, except when the model can be expressed as linear regression, the computation of the estimate requires an iterative search of the minimum of the cost function. The cost function can have multiple minima and it is a main challenge in system identification research to invent algorithms which can guarantee, or at least increase the chances that the estimate converges to the global minimum. Hence, while applying the iterative minimization is straight forward, each type of model structure needs a good initialization algorithm from which the iterative minimization starts. This is further described in [J-Sj-8].

The Wiener-Hammerstein model is one example of a more general nonlinear class of block-oriented models and many approaches for estimating such models have been published. Early results can be found in [2] and [4]. The first one of these also contains many references to pioneer works. A stochastic embedding of the estimation problem is given in [5] and the Maximum Likelihood estimate is formulated. Recursive estimation of MIMO Wiener-Hammerstein models is investigated in [3]. In these publications no hints are given for the initialization. In [6] an iterative initialization procedure is proposed which requires specially designed periodic excited input signals. This experimental requirement is relaxed in [11]. Techniques where the need of initial values is avoided by restricting the allowed model complexity are given in [1, 15, 16]. In [8] an approach is presented which applies for the case that the linear sub-models can be described as FIR models. Here we are aiming at less restrictive initialization algorithms which can be applied using data without special restrictions, and with fairly general assumptions on the linear blocks and the nonlinearity.

A key problem in identifying Wiener-Hammerstein models is the initial estimates of the two linear blocks. Not only the degree of the two sub-systems need to be determined, also values of the parameters describing the poles and zeros need good initial values so that the parameter estimation algorithm has a good chance to end up in a good local minimum. This is illustrated in [18] where the prediction error method is applied starting at random, stable, initializations of the two sub-systems. Depending on the start value the estimate converges toward one of many local minima.

There is, however, no reason to start with random positions of the poles and the zeros in the two linear blocks. In [10] it is shown that linear system identification applied to data from a Wiener-Hammerstein system, then, when the number of data goes to infinity, the obtained model equals a scaled version of the combined linear dynamics. Using this insight, and linear system identification tools to obtain the BLA, it remains to divide the poles and the zeros between the two linear blocks to obtain a good initialization. Several suggested initialization algorithms are based on this insight.

At this point, we can conclude the system identification problem to be a mixed integer problem: To decide the division of the poles and the zeros (integer decision) and to identify the nonlinearity between the linear blocks (continuous minimization problem).

The simplest approach to this mixed integer problem is to try all possible divisions of the poles and the zeros. In this way, a large set of possible initializations of the linear blocks are obtained. For each one of them, the nonlinearity is identified and the performance can be compared to select the best initialization. This approach was presented in [J-Sj-8] and although it is a trivial approach, it outperform all other methods published up to then. In [J-Sj-8] it is also shown that if the nonlinearity is linear in the parameters then the fitting of the nonlinearity is a least-squares problem. This makes it feasible to evaluate a large set of tentative divisions of the poles and the zeros in a reasonable time, and it is argued that this method is acceptable up to model orders 10-12.

The results in [J-Sj-8] has inspired several researchers, especially at VUB in

Brussels, to develop algorithms with the advantages but avoiding having to test a lot of possible partitioning of the poles and the zeros. In [J-Sj-7] an algorithm developed by L. Leuwers is presented where *all poles and zeros are offered to both linear blocks*. This is done by forming parameterized estimates of the un-measured signals $v(t)$ and $w(t)$, as defined in Figure 1. First a split is made so that the first linear block is described as a linear expansion with the poles as basis functions, and the second linear block is described by an inverse expansion with the zeros as basis functions. In that way, both linear blocks have the total dynamics of the BLA model available. The input signal is filtered through the first linear block, and the output signal is filtered through the inverse of the second block. Then the parameters of the two expansions are estimated together with parameters describing the nonlinearity in a Total-Least-Square problem, for which efficient algorithms exist. Weaknesses of this algorithms are that the zeros at the first linear block, and poles at the second block do not necessarily coincide with those in the linear model. Also, disturbances on the output influence the estimate so the result is asymptotically biased.

Another interesting approach where all poles and zeros are offered to both linear blocks is presented in [17]. There, L. Vanbeylen relax the mixed integer problem and parameterize the placement of each pole and zero with real valued parameters, $\alpha = \{\alpha_1, \ldots, \alpha_{n_A}\}$, and $\beta = \{\beta_1, \ldots, \beta_{n_B}\}$, as

$$\hat{G}_W(q^{-1}, \alpha, \beta) = \frac{\prod_{i=1}^{n_B}(1 - z_i^{BLA} q^{-1})^{\beta_i}}{\prod_{i=1}^{n_A}(1 - p_i^{BLA} q^{-1})^{\alpha_i}}, \quad \hat{G}_H(q^{-1}, \alpha, \beta) = \frac{\prod_{i=1}^{n_B}(1 - z_i^{BLA} q^{-1})^{1-\beta_i}}{\prod_{i=1}^{n_A}(1 - p_i^{BLA} q^{-1})^{1-\alpha_i}}, \tag{1}$$

where z_i^{BLA} and p_i^{BLA} are, respectively, zero and pole of the BLA. The indices n_A and n_B denote the degree of the BLA. In that way, all poles and zeros are offered to both linear blocks. The parameters α and β are then estimated together with the parameters of the nonlinearity and parameters becoming 1 indicate that the corresponding pole or zero should be placed in the first linear block, and those becoming 0 belongs to the second linear block.

Given N data from the system, inputs and outputs ,$\{u(t), y((t)\}_{\{t=1\}}^N$, the optimization problem for the estimation of α and β then becomes

$$\min_{\alpha,\beta,\theta_{NL}} V_N(\theta), \quad V_N(\theta) = \frac{1}{N}\sum_{t=1}^{N}(y(t) - \hat{y}(t, \alpha, \beta, \theta_{NL}))^2. \tag{2}$$

and

$$\hat{y}(t, \alpha, \beta, \theta_{NL}) = \hat{G}_W(q^{-1}, \alpha, \beta) f(\theta_{NL}, \hat{G}_H(q^{-1}, \alpha, \beta)u(t)) \tag{3}$$

and θ_{NL} are the parameters describing the static nonlinearity, $f(\theta_{NL}, \cdot)$.

In the time domain, the transfere functions (1) are not well defined for real values of α and β so it is not straight-forward to formulate the estimation algorithm.

The clever insights used in [17] was to use frequency domain for the linear fraction transfere functions, and time domain for the nonlinearity. The method provides good results in terms of number of iterative optimizations needed. However, there are no guarantees that local minima are avoided.

The main idea for this research proposal is to investigate the possibilities using fractional description, like (1), for the positioning of the poles and zeros in block models containing multiple possible positioning of them (of which the Wiener-Hammerstein model is the simplest example). We will, however, mainly use the time domain and handle the fractions by Taylor expand the functions and in this way obtain large linear regression problems. To avoid huge algebraic expressions, this is described bellow with an example, taken from [7].

Consider a Wiener-Hammerstein system described in the following way

$$\begin{aligned} v(t) &= \frac{(1-b_1q^{-1})}{(1-a_1q^{-1})}u(t), \\ w(t) &= f(\theta_{NL}, v(t)) = \theta_1 v(t) + \theta_2 v^2(t), \\ y(t) &= \frac{1}{1-a_3q^{-1}}w(t). \end{aligned} \tag{4}$$

Assume for simplicity, that the BLA is exact,

$$G_{BLA}(q^{-1}) = \frac{(1-b_1q^{-1})}{(1-a_1q^{-1})(1-a_2q^{-1})}. \tag{5}$$

Therefore, (1) becomes

$$\hat{G}_W(q^{-1},\alpha,\beta) = \frac{(1-a_3q^{-1})^{\beta_1}}{(1-a_1q^{-1})^{\alpha_1}(1-a_2q^{-1})^{\alpha_2}}, \tag{6}$$

$$\hat{G}_H(q^{-1},\alpha,\beta) = \frac{(1-a_3q^{-1})^{1-\beta_1}}{(1-a_1q^{-1})^{1-\alpha_1}(1-a_2q^{-1})^{1-\alpha_2}}. \tag{7}$$

Now, expanding $G_W(q^{-1},\alpha,\beta)$ and $G_H(q^{-1},\alpha,\beta)$ give the approximations

$$\begin{aligned} \tilde{G}_W(q^{-1},\alpha,\beta) =& 1 + A_1(\alpha,\beta)q^{-1} + \cdots + A_{n_1}(\alpha,\beta)q^{-n_1} + \\ &+ d_{W_1}q^{-(n_1+1)} + \cdots + d_{W_{n_2}}q^{-n} \end{aligned} \tag{8}$$

and

$$\begin{aligned} \tilde{G}_H(q^{-1},\alpha,\beta) =& 1 + B_1(\alpha,\beta)q^{-1} + \cdots + B_{n_1}(\alpha,\beta)q^{-n_1} + \\ &+ d_{H_1}q^{-(n_1+1)} + \cdots + d_{H_{n_2}}q^{-n}. \end{aligned} \tag{9}$$

The expansion order n must be high enough so that the approximation error is negligible. There is also of interest to divide the expansions into two parts, where the first n_1 coefficients are needed to recover the values of the original parameters α, β. Typically $n_1 < n$. The predictor (3) can now be expressed as

$$\hat{y}(t,\theta) = \tilde{G}_W(q^{-1},\alpha,\beta) f(\theta_{NL}, \tilde{G}_H(q^{-1},\alpha,\beta)u(t)). \tag{10}$$

In (8) $A_1(\alpha,\beta)$, ..., $A_{n_1}(\alpha,\beta)$ are the coefficients of the Taylor series necessary to re-obtain the values of α, β, while $d_W = [d_{W_1}, ..., d_{W_{n_2}}]$, $d_H = [d_{H_1}, ..., d_{H_{n_2}}]$ are dummy coefficients.

There is a natural symmetry between the two expansions,

$$A_i(\alpha,\beta) = \frac{\hat{G}_W^{(i)}(0,\alpha,\beta)}{i!}, \quad B_i(\alpha,\beta) = A_i(1-\alpha, 1-\beta), \tag{11}$$

where $\hat{G}_W^{(i)}(0,\alpha,\beta)$ denotes the i-th derivative of $\hat{G}_W$ with respect to the delay operator, evaluated in 0.

Now, with $n_1 = 3$, the predictor for system (4) becomes

$$\hat{y}(t) = \hat{w}(t) + B_1\hat{w}(t-1) + B_2\hat{w}(t-2) + B_3\hat{w}(t-3), \tag{12}$$

where $\hat{w}(t)$ is the output of the nonlinearity and can be expressed as

$$\begin{aligned}\hat{w}(t) = \theta_1 u(t) + \theta_2 u^2(t) + A_1\theta_1 u(t-1) + 2A_1\theta_2 u(t)u(t-1) + A_1^2\theta_2 u^2(t-1) + \\ + A_2\theta_1 u(t-2) + 2A_2\theta_2 u(t)u(t-2) + 2A_1A_2\theta_2 u(t-1)u(t-2) + A_2^2\theta_2 u^2(t-2) + \\ + A_3\theta_1 u(t-3) + 2A_3\theta_2 u(t)u(t-3) + 2A_1A_3\theta_2 u(t-1)u(t-3) + \\ + 2A_2A_3\theta_2 u(t-2)u(t-3) + A_3^2\theta_2 u^2(t-3).\end{aligned} \tag{13}$$

For simplicity, in (12) and (13) the dummy parameters have been omitted, it is messy enough anyway. The main message is, however, fairly clear, combining (12) and (13) gives a linear regression formulation if one re-parameterize and introduce regressors consisting of monomials in shifted versions of $u(t)$. Eg, one of the regressors is $u(t-3)u(t-4)$, and the corresponding expression which should be replaced with a new parameter is $2A_2A_3B_1$.

To sum up, the example shows that it is possible to express the problem of identifying the division of the poles and zeros of the BLA between the two linear blocks as a continuous identification problem. Due to the expansion and the nonlinearity, the expressions becomes messy. However, the principle is straightforward and it has been implemented in *Mathematica* so that one does not need to see the huge intermediate expressions. In [7] the method is also applied to an example.

Nevertheless, there are many open issues, and the purpose of this proposal is to fill some them.

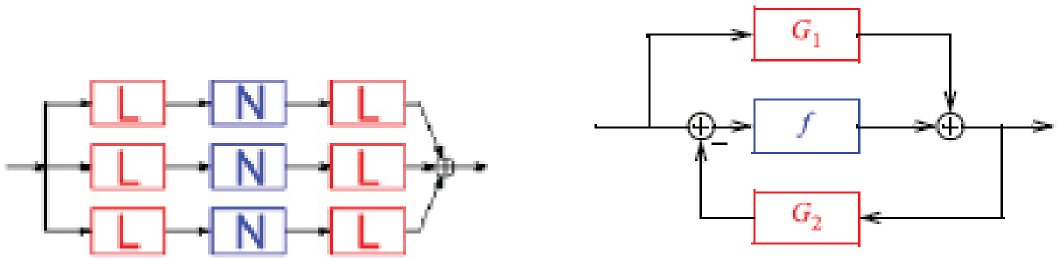

Figure 2: a) A parellel Wiener-Hammerstein model structure . b) A Recurrent block based nonlinear model structure. Figures from [12].

So far we have focused on the Wiener-Hammerstein model. There exist, however, many other model structures with similar initialization problems. For example, the parallel Wiener-Hammerstein models, illustrated in Figure 2 a). [13] describes an identification scheme which requires multiple input signals, and which in the end is very elaborative. We intend to investigate how the described technique can be used to obtain better algorithms.

Another class of block models we intend to investigate are those with an internal feedback, an example of such a model is shown in Figure 2 b).

3 Project description

In the previous section, the main research topic was described, namely to investigate the possibilities and the properties of algorithms based on series expansions describing the division of poles and zeros in the initialization step of nonlinear block based models.

There are a number of research questions to investigate:

- It can be shown that the linear regression formulation becomes very large. A moderate sized problem can easily give a LS problem with 10 000 regressors. How can this be handled, making use of the fact that we need only a few of all the parameters to obtain the α, β?
- Can it be better to stay with the original parameters instead of the LS formulation? Can local minima still be avoided?
- How connects the risk of local minima in the original parameterization with the question of uniqueness when the α, β are to be calculated from the LS estimate?

- How should the expansion order n be chosen dependent on the BLA?
- How should n_1 be chosen to make it possible to obtain the values of α, β?
- Statistical properties of the obtained initialization, can the risk of miss-classifying a pole or a zero be estimated?
- Develop a formalism for describing the developed algorithms.

3.1 Preliminary time plan

year 1 Investigate and describe the algorithm for Wiener-Hammerstein model. Investigate the LS formulation, how the problem scale with respect to the order of the BLA and the complexity if the nonlinear model. Search for possibilities to circumvent the problem with a large LS problem. Compare with how other algorithms scale. Validate theoretical results with computer simulations.

year 2 Statistical properties. What are the possibilities to apply the algorithms to other block based model structures? Start with the parallel Wiener-Hammerstein model.

year 3 Licentiate degree. Continue expanding results to other model structures and investigate the properties of the algorithms. Guest research visit. Possible at VUB, but other alternatives could also be possible.

year 4 and 5 Depending on the results up to here, the most interesting remaining questions are investigated further.

4 Significance

Within the field of nonlinear system identification the block based models is one of the groups of models which has received very much attention. Faster and more reliable estimation of models is essentially for developing and improving performance of functionality that run independent of a supervisor. Hence, better algorithms for block based models can be of significant importance in, eg, many industrial processes to increase the performance in all possible ways.

5 Preliminary results

The project leader has a long background in nonlinear system identification research going back to his Ph.D which was published 1995. The academic year 2009-2010 he focused on identification of block based models during a sabbatical with Johan Schoukens at VUB in Belgium. The hosting research group has a long tradition of work on block based models, and the project leader had the opportunity to cooperate with several researchers. Among other, the publications [J-Sj-8], [J-Sj-7] and [J-Sj-6] contains results on identification of block based models from that sabbatical stay.

The example in previous section was taken from [7] where also some more details about the approach are explained.

6 International and national cooperation

There are close connections with the ELEC research group at VUB, Belgium. Except that, good European and international contacts exists with in the system identification community, among other ways, through the European Research Network System Identification (ERNSI) `http://ernsi.s3.kth.se/` which organizes a yearly workshop where ideas and contacts are exchanged.

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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	Jonas Sjöberg	20
2	Other personnel without doctoral degree	doktorand	80

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Jonas Sjöberg	10	134	139	143	148	564
2	Other personnel without doctoral degree	Doktorand	80	481	498	516	534	2,029
	Total			615	637	659	682	2,593

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	44	46	47	49	186
	Total	44	46	47	49	186

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Konferensresor	vetenskapliga	20	20	40	40	120
2	Forskningsresor	sommarskoloretc	20	20	20	20	80
3	litteratur	böcker	2	2	2	2	8
4	Förbrukningsmaterial	dator	20				20
5	Direkta IT-kostnader		14	14	15	15	58
	Total		76	56	77	77	286

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	615	637	659	682	2,593		2,593
Running costs	76	56	77	77	286		286
Depreciation costs					0		0
Premises	44	46	47	49	186		186
Subtotal	735	739	783	808	3,065	0	3,065
Indirect costs	226	234	242	250	952		952
Total project cost	961	973	1,025	1,058	4,017	0	4,017

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

Budgeten avser att finansiera en doktorand samt handledning av denna. Utöver handledning avser projektledaren att forska själv i projektet vilket ger en aktivitetsgrad på 20% i projektet. Därför är alla kostnadsposter rätt så rättframma.

Lön projektledare, 10% övriga 10% täcks med interna medel.
Lön doktorand 80%. Övriga 20% täcks med undervisningsmedel och motsvarande arbetstid läggs på undervisning.
Kontor: kostnad för arbetsplats för doktoranden + proskarledaren (andel av kostnaden i relation med aktivitetsgrad)
Konferensresor: för att presentera resultat från projektet på vetenskapliga konferenser.
Forskningsresor: för att besöka sommarskola, besöka annan institution som gäst.
Litteratur: fackböcker
Förbrukningsmaterial: dator + kringutrustning till doktoranden.
Direkta IT-kostnader: infrastrukturkostnad, fördelas enlikt schablon inom universitetet.
Indirekta kostnader: Kostnader för gemensamma universitetresurser (exklusive IT) fördelas med schablon.

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

Jonas Sjöberg

1. Higher education qualifications

1989 **Masters of Science, Applied Physics**, *Uppsala University*, Uppsala, Sweden.

2. Doctoral degree:

1995 **Ph.D. in Electrical Engineering**, *Linköping University*, Sweden.
Title: "Nonlinear System Identification with Neural Networks". Advisor: Prof. L. Ljung.

3. Postdoctoral positions:

1995- 1996 **Post-doc**, *Dept. of Chemical Engineering*, Swiss Federal Institute of Technology, Zürich, Switzerland.

4. Qualification required for appointments as a docent

2000 **Swedish Docent degree**, *Chalmers.*

5. Current position

2001- present **Professor, approximately 50%-60% time for research.**, *Department of Signals and Systems*, Chalmers University of Technology, Göteborg, Sweden. Leading a research group of approximately 15 persons of which 5 are senior researchers, 3 post docs, and the rest are Ph.D. students.

6. Previous positions and periods of appointment

2009-2010 **Guest researcher**, *Department of Fundamental Electricity and Instrumentation*, Faculty of Engineering, Vrije Universiteit Brussel, Belgium (12 months).

2000– 2001 **Associate professor**, *Department of Signals and Systems*, Chalmers University of Technology, Göteborg, Sweden.

1996– 2000 **Assistant professor**, *Department of Signals and Systems*, Chalmers.

1998 **Guest researcher**, Technion, Haifa, Israel (6 months).

1997 **Guest researcher**, *Institute for Econometrics, Operations Research and System Theory, Vienna University of Technology, Austria (6 months).*

1996 **Visiting lecturer, summer course**, *Computer Science Department*, Linköping University.

7. Interruption in research

2001-2012 **Parental leave:**, 60% during 6 months 2001, 100% during 9 months 2006, 100% during 9 months 2012. No essential reduction of teaching during these leave of absence.

2005-2010 **Head of Programme**, in Automation and Mechatronics at Chalmers (30% duty). No reduction of teaching duties due to this commission. This duty gave valuable overview of the teaching body of Chalmers, the process of managing education and the importance of motivating teachers as well as students.

2001-present **Leadership responsibilities**, Jonas is leading a research group of 15 persons. This has given valuable experience in leadership.

8. Supervision

Supervised Ph.D Projects, main supervisor

2012 **M. Ali**.

2012 **N. Murgovski**.

2011 **M. Brännström**.

2004 **J. Hellgren**.

2000 **L.S.H. Ngia**.

4 completed licentiate degrees as main supervisor.
Ongoing Ph.D projects where Jonas is the main supervisor: 3, co-supervisor: 4

Postdoc supervision

2012–2015 **Gabriel Rodrigues de Campos**, *Chalmers*, Gothenburg, Sweden.

2012–2014 **Nikolce Murgovski**, *Chalmers*, Gothenburg, Sweden.

2009–2011 **Esteban Gelso**, *Chalmers*, Gothenburg, Sweden.

2009–2010 **Anna Marconato**, *Department of Fundamental Electricity and Instrumentation*, Faculty of Engineering, Vrije Universiteit Brussel, Belgium.

9. Other information of relevance to the application

Awards and special commissions

2011 **Volvo Cars Technology Award**.

2011-present **Scientific evaluator**, for VINNOVA, FFI - Vehicle and Traffic Safety.

2010-present **Steering group member**, of Chalmers's 'Area of advance, Transportation, with focus on trafic safety.

2005-2010 **Head of Programme**, in Automation and Mechatronics at Chalmers (30% duty).

1999-2008 **Associate editor of Control Engineering Practice**.

1998 **Lady Davis postdoctoral scholarship**.

1997 **Stipend**, from the "Ericsson funding for supporting Electrical Engineering".

1996 **Stipend**, from "The foundation of Bernt Järmark's memory".

1990 **Stipend**, from the "Ericsson funding for supporting Electrical Engineering".

1987-1989 **Scholarship**, from the Swiss Government for Academic Studies in Switzerland.

Entrepreneurial achievements

Jonas Sjöberg is the author of Wolfram Research's Neural Network package, an add-on tool for mathematical software tool *Mathematica*, http://www.wolfram.com/products/applications/neuralnetworks. More than 1000 users.

Experience of communicating results with stakeholders/end users

Most research projects are together with industrial partners integrated with a process for knowledge transfer. Jonas regularly give courses for industry participants. He is often engaged as speaker to spread information outside his area of expertise. For example, he participated in Vetenskapsfestivalen 2012 (http://vetenskapsfestivalen.se/), and the seminar day organized by the magazine Ny Teknik, "Smarta fordon – ny teknik för aktiv och passiv säkerhet", 2013, speaker at Chalmers's Transport Day 2010, http://www.chalmers.se/en/areas-of-advance/Transport/FilmTransportdagen/Pages/Traffic-Safety—Accident-Avoidance.aspx

Publication list

Publications Jonas Sjöberg

Number of citations are based on Google Scholar.

1. Peer-Reviewed Journal Papers 2008–2015

[J-Sj-1] A. Marconato, J. Sjöberg, J.A.K. Suykens, and J. Schoukens. Improved initialization for nonlinear state-space modeling. *Instrumentation and Measurement, IEEE Transactions on*, 63(4):972–980, 2014. Number of citations: **2**

[J-Sj-2] M. Brännström, E. Coelingh, and J. Sjöberg. Decision-making on when to brake and when to steer to avoid a collision. *International journal of vehicle safety*, 7(1):87–106, 2014. Number of citations: **7**

[J-Sj-3] M. Ali, P. Falcone, C. Olsson, and J. Sjöberg. Predictive prevention of loss of vehicle control for roadway departure avoidance. *Intelligent Transportation Systems, IEEE Transactions on*, 14(1):56–68, 2013. Number of citations: **6**

[J-Sj-4] M. Ali, E. Gelso, and J. Sjöberg. Automotive threat assessment design for combined braking and steering maneuvers. *Vehicular Technology, IEEE Transactions on*, PP(99):1–1, 2013. Number of citations: **2**

[J-Sj-5] N. Murgovski, L. Mårdh Johannesson, and J. Sjöberg. Engine on/off control for dimensioning hybrid electric powertrains via convex optimization. *Vehicular Technology, IEEE Transactions on*, 62(7):2949–2962, 2013. Number of citations: **15**

[J-Sj-6] (*) A. Marconato, J. Sjöberg, and J. Schoukens. Initialization of nonlinear state-space models applied to the Wiener-Hammerstein benchmark. *Control Engineering Practice*, 20(11):1126 – 1132, 2012. Special Section: Wiener-Hammerstein System Identification Benchmark. Number of citations: **6**

[J-Sj-7] (*) J. Sjöberg, L. Lauwers, and J. Schoukens. Identification of Wiener-Hammerstein models: Two algorithms based on the best split of a linear model applied to the SYSID'09 benchmark problem. *Control Engineering Practice*, 20(11):1119 – 1125, 2012. Special Section: Wiener-Hammerstein System Identification Benchmark. Number of citations: **8**

[J-Sj-8] (*) J. Sjöberg and J. Schoukens. Initializing Wiener-Hammerstein models based on partitioning of the best linear approximation. *Automatica*, 48(2):353–359, 2012. Number of citations: **18**

[J-Sj-9] N. Murgovski, L. Johannesson, J. Sjöberg, and B. Egardt. Component sizing of a plug-in hybrid electric powertrain via convex optimization. *Journal of Mechatronics*, 1:106–120, 2012. Number of citations: **40**

[J-Sj-10] P. Falcone, M. Ali, and J. Sjöberg. Predictive threat assessment via reachability analysis and set invariance theory. *Intelligent Transportation Systems, IEEE Transactions on*, 12(4):1352 –1361, dec. 2011. Number of citations: **22**

[J-Sj-11] N. Murgovski, J. Sjöberg, and J. Fredriksson. A methodology and a tool for evaluating hybrid electric powertrain configurations. *Int. J. Electric and Hybrid Vehicles*, 3(3):219–245, 2011. Number of citations: **12**

[J-Sj-12] M. Brännström, E. Coelingh, and J. Sjöberg. Model-based threat assessment for avoiding arbitrary vehicle collisions. *IEEE Transactions on Intelligent Transportation Systems*, 11(3):658–669, 2010. Number of citations: **51**

[J-Sj-13] J. Sjöberg, P.O. Gutman, M. Agarwal, and M. Bax. Nonlinear controller tuning based on a sequence of identifications of linearized time-varying models. *Control Engineering Practice*, 17(2):311–321, Feb. 2009. Number of citations: **14**

2. Refereed Conference Papers 2008–2015

[C-Sj-1] Gabriel Rodrigues de Campos, Paolo Falcone, Henk Wymeersch, Robert Hult, and Jonas Sjöberg. Cooperative receding horizon conflict resolution at traffic intersections. In *IEEE Conference on Decision and Control*, 2014. Number of citations: **0**

[C-Sj-2] Soma Tayamon and Jonas Sjöberg. Modelling of selective catalytic reduction systems using discrete-time linear parameter varying models. *Proceedings of the 19th IFAC World Congress*, 2014. Number of citations: **1**

[C-Sj-3] Gabriel Rodrigues de Campos, Paolo Falcone, and Jonas Sjoberg. Autonomous cooperative driving: A velocity-based negotiation approach for intersection crossing. In *Intelligent Transportation Systems-(ITSC), 2013 16th International IEEE Conference on*, pages 1456–1461. IEEE, 2013. Number of citations: **9**

[C-Sj-4] Malin Sundbom, Paolo Falcone, and Jonas Sjoberg. Online driver behavior classification using probabilistic arx models. In *Intelligent Transportation Systems-(ITSC), 2013 16th International IEEE Conference on*, pages 1107–1112. IEEE, 2013. Number of citations: **1**

[C-Sj-5] Julia Nilsson, Mohammad Ali, Paolo Falcone, and Jonas Sjöberg. Predictive manoeuvre generation for automated driving. *16th International IEEE Annual Conference on Intelligent Transportation Systems*, 2013. Number of citations: **4**

[C-Sj-6] Julia Nilsson and J Sjoberg. Strategic decision making for automated driving on two-lane, one way roads using model predictive control. In *Intelligent Vehicles Symposium (IV), 2013 IEEE*, pages 1253–1258. IEEE, 2013. Number of citations: **3**

[C-Sj-7] Stefan Bergquist, Christian Grante, Jonas Fredriksson, and Jonas Sjöberg. Automation for improved safety in roadside construction. In *Proceedings of the 30th International Symposium on Automation and Robotics in Construction and Mining*, volume 2013, 2013. Number of citations: **1**

[C-Sj-8] M. Ali, P. Falcone, and J. Sjoberg. Threat assessment design under driver parameter uncertainty. In *Decision and Control (CDC), 2012 IEEE 51st Annual Conference on*, pages 6315–6320, Dec. Number of citations: **5**

[C-Sj-9] N. Murgovski, L. Johannesson, and J. Sjöberg. Convex modeling of energy buffers in power control applications. In *IFAC Workshop on Engine and Powertrain Control Simulation and Modeling*, pages 92–99, 2012. Number of citations: **16**

[C-Sj-10] N. Murgovski, L. Johannesson, A. Grauers, and J. Sjöberg. Dimensioning and control of a thermally constrained double buffer plug-in hev powertrain. In *51st IEEE Conference on Decision and Control*, pages 6346–6351, 2012. Number of citations: **7**

[C-Sj-11] H. Hjalmarsson and J. Sjöberg. A Mathematica toolbox for signals, systems and identification system identification. In *Proc. 16th IFAC Symposium on System Identification Square - Brussels Meeting Centre, Belgium*, pages 1541–1546, July 2012. Number of citations: **0**

[C-Sj-12] A. Marconato, J. Sjöberg, J. Suykens, and J. Schoukens. Separate initialization of dynamics and nonlinearities in nonlinear state-space models. In *Proc. of 2012 IEEE International Instrumentation and Measurement Technology Conference (I2MTC 2012)*, 2012. Number of citations: **2**

[C-Sj-13] A. Marconato, J. Sjöberg, J. Suykens, and J. Schoukens. Identification of the silverbox benchmark using nonlinear state-space models. In *Proc. of the 16th IFAC Symposium on System Identification (SYSID 2012)*, 2012. Number of citations: **2**

[C-Sj-14] M. Ali, P. Falcone, and J. Sjöberg. Model-based threat assessment for lane guidance systems. In *American Control Conference, San Francisco, CA, USA*, pages 4586–4591, June 2011. Number of citations: **1**

[C-Sj-15] M. Ali, P. Falcone, and J. Sjöberg. Model-based threat assessment in semi-autonomous vehicles with model parameter uncertainties. In *50th IEEE Conference on Decision and Control and European Control Conference, Orlando, FL, USA*, Dec. 2011. Number of citations: **1**

[C-Sj-16] M. Ali, C. Olsson, and J. Sjöberg. Real-time implementation of a novel safety function for prevention of loss of vehicle control. In *IEEE Intelligent Transportation Systems Conference (ITSC), Washington, USA*, Oct. 2011. Number of citations: **0**

[C-Sj-17] M. Brännström, E. Coelingh, and J. Sjöberg. Decision making on when to brake and when to steer to avoid a collision. In *First International Symposium on Future Active Safety Technology toward zero-traffic-accident, Sept., Tokyo, Japan*, 2011. Number of citations:

[C-Sj-18] M. Brännström, J. Sjöberg, L. Helgesson, and M. Christiansson. A real-time implementation of an intersection collision avoidance system. In *Conference: 18th IFAC World Congress, Milano, Italy*, 2011. Number of citations: **2**

[C-Sj-19] E. Gelso, M. Ali, and J. Sjöberg. Threat assessment for driver assistance systems using interval-based techniques. In *Conference: 18th IFAC World Congress, Milano, Italy*, 2011. Number of citations: **1**

[C-Sj-20] B. Mirkin, P.O. Gutman, and J. Sjöberg. Output-feedback mrac with reference model tolerance of nonlinearly perturbed delayed plants. In *Conference: 18th IFAC World Congress, Milano, Italy*, 2011. Number of citations: **4**

[C-Sj-21] N. Murgovski, L. Johannesson, J. Hellgren, B. Egardt, and J. Sjöberg. Convex optimization of charging infrastructure design and component sizing of a plug-in series hev powertrain. In *Conference: 18th IFAC World Congress*, Milano, Italy, 2011. Number of citations: **8**

[C-Sj-22] J. Sjöberg and J. Schoukens. Initializing Wiener-Hammerstein models based on partitioning of the best linear approximation. In *Conference: 18th IFAC World Congress, Milano, Italy*, 2011. Number of citations: **18**

[C-Sj-23] D. Bauer and J. Sjöberg. Fast and good initialization of rbf networks. In *Proceeding of the 18th European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning, Bruges, Belgium*, April 2010. Number of citations: **0**

[C-Sj-24] S. Mohajerani and J. Sjöberg. On initialization of iterativealgorithms for nonlinear arx models. In *In proceedings of 8th IFAC Symposium on Nonlinear Control Systems, Milano, Italy*, September 2010. Number of citations: **0**

[C-Sj-25] N. Murgovski, J. Sjöberg, J. Fredriksson, and B. Norén. Hybrid powertrain concept evaluation using optimization. In *In proceedings of the 25th International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium & Exposition,(EVS25)*, Shenzhen, China, Nov. 2010. Number of citations: **1**

[C-Sj-26] N. Murgovski, J. Sjöberg, and J. Fredriksson. Automatic simplication of hybrid powertrain models for use in optimization. In *In proceedings of AVEC10, 10th International Symposium on Advanced Vehicle Control*, 2010. Number of citations: **1**

[C-Sj-27] P. Falcone, M. Ali, and J. Sjöberg. Set-based threat assessment in semi-autonomous vehicles. In *In proceedings of 10th IFAC Symposium, Advances in Automotive Control, Munich, Germany*, July 2010. Number of citations: **0**

[C-Sj-28] N. Murgovski, J. Sjöberg, and J. Fredriksson. A tool for generating optimal control laws for hybrid electric powertrains. In *In proceedings of 10th IFAC Symposium, Advances in Automotive Control, Munich, Germany*, Loughborough, UK, July 2010. Number of citations: **0**

[C-Sj-29] J. Nuevo, I. Parra, J. Sjöberg, and L. Bergasa. Estimating surrounding vehicles' pose using computer vision. In *In proceeding of 13th International IEEE Conference on Intelligent Transportation Systems, ITSC 2010, Madeira, Portugal*. IEEE, September 2010. Number of citations: **9**

[C-Sj-30] J. Sjöberg, E. Coelingh, M. Ali M. Brännström, and P. Falcone. Driver models to increase the potential of automotive active safety functions. In *Proceedings of 18th European Signal Processing Conference, Aalborg, Denmark*, August 2010. Number of citations: **2**

[C-Sj-31] M. Ali and J. Sjöberg. Impact of different vehicle models on threat assessment in critical curve situations. In *21st International Conference on Enhanced Safety of Vehicles, Stuttgart, Germany*, June 2009. Number of citations: **3**

[C-Sj-32] M. Ali, P. Falcone, and J. Sjöberg. A predictive approach to roadway departure prevention. In *21st IAVSD Symposium on Dynamics of Vehicles on Roads and Tracks, Stockholm*, August 2009. Number of citations: **7**

[C-Sj-33] M. Ali, C. Olsson, and J. Sjöberg. Towards predictive yaw stability control. In *Intelligent Vehicles Symposium, Xi'an, Shaanxi, China*. IEEE, June 2009. Number of citations:

[C-Sj-34] M. Brännström, J. Sjöberg, and E. Coelingh. Threat assessment for avoiding collisions with turning vehicles. In *Intelligent Vehicles Symposium, Xi'an, Shaanxi, China*. IEEE, June 2009. Number of citations: **3**

[C-Sj-35] J. Sjöberg and H. Hjalmarsson. A system, signal, and identification toolbox in Mathematica with symbolic capabilities. In *Preprint, 15th IFAC Symposium on System Identification Saint-Malo, France*, pages 747–751, July 2009. Number of citations: **2**

[C-Sj-36] J. Sjöberg and J. Schoukens. Estimates of an upper limit of the number of parameters in nonlinear model structures. In *Conference: 15th IFAC Symposium on System Identification Saint Malo, France*, 2009. Number of citations: **0**

[C-Sj-37] J. Nilsson, P.Falcone, J. Vinter, J. Sjöberg, L. Nilsson, and J. Jacobson. A brief paper on improving active safety systems via hmi and dependability analysis. In *3rd IET International Conference on System Safety*, 2008. Number of citations: **1**

[C-Sj-38] J. Sjöberg, P-O. Gutman, M. Agarwal, and M. Bax. Iterative feedback tuning for nonlinear systems based on identification of linearized time-varying models. In *Proceedings of the 9th Biennial ASME Conference on Engineering Systems Design and Analysis ESDA 2008*, Haifa, Israel, July 2008. Number of citations: **0**

[C-Sj-39] M. Brännström, J. Sjöberg, and E. Coelingh. A situation and threat assessment algorithm for a rear-end collision avoidance system. In *Intelligent Vehicles Symposium, Eindhoven, The Netherlands*, pages 102–107. IEEE, June 2008. Number of citations: **13**

6. Patents

[P1] M. Brännström, E. Coelingh, and J. Sjöberg. Method and system for avoiding host vehicle collisions with a target. EP Patent 2,208,654, 2010. Number of citations: **?**

[P2] M. Ali, C. Olsson, and J. Sjöberg. Method and system for predictive yaw stability control for automobile. EP Patent 2,261,093, 2010. Number of citations: **?**

7. Computer Software

Jonas Sjöberg is the author of Wolfram Research´s Neural Network package, an add-on application package for neural network computations under the general mathematical program *Mathematica*. This package contains state-of-the-art algorithms and is accompanied with a 300-pages manual including tutorial chapters for beginners as well as advanced examples illustrating the capabilities of the package.
`http://www.wolfram.com/products/applications/neuralnetworks/`. More than 1000 users.

9. Five most cited publications

[Sj-1] (*) J. Sjöberg, Q. Zhang, L. Ljung, A. Benveniste, B. Deylon, P-Y. Glorennec, H. Hjalmarsson, and A. Juditsky. Non-linear black-box modeling in system identification: a unified overview. *Automatica*, 31(12):1691–1724, 1995. Number of citations: **1536**

[Sj-2] A. Juditsky, H. Hjalmarsson, A. Benveniste, B. Deylon, L. Ljung, J. Sjöberg, and Q. Zhang. Non-linear black-box models in system identification : Mathematical foundations. *Automatica*, 31(12), December 1995. Number of citations: **336**

[Sj-3] J. Sjöberg and L. Ljung. Overtraining, regularization, and searching for minimum with application to neural nets. *Int. J. Control*, 62(6):1391–1407, 1995. Number of citations: **229**

[Sj-4] J. Sjöberg, H. Hjalmarsson, and L. Ljung. Neural networks in system identification. In *Preprint, 10th IFAC Symposium on System Identification, Copenhagen*, volume 2, pages 49–72, 1994. Number of citations: **126**

[Sj-5] L.S.H. Ngia and J. Sjöberg. Efficient training of neural nets for nonlinear adaptive filtering using a recursive levenberg-marquardt algorithm. *IEEE Trans. on Signal Processing*, 48(7):1915–1927, July 2000. Number of citations: **117**

CV

Name: Jonas Sjöberg	**Doctorial degree:** 1995-05-12
Birthdate: 19640228	**Academic title:** Professor
Gender: Male	**Employer:** Chalmers tekniska högskola

Research education

Dissertation title (swe)
Olinjär systemidentifiering med neuronnät

Dissertation title (en)
Nonlinear System Identification with Neural Networks

Organisation	Unit	Supervisor
Linköpings universitet, Sweden Sweden - Higher education Institutes	Institutionen för systemteknik (ISY)	Lennart Ljung

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20202. Reglerteknik	0345-7524/91-7871-534-2	1995-05-12

Publications

Name: Jonas Sjöberg	**Doctorial degree:** 1995-05-12
Birthdate: 19640228	**Academic title:** Professor
Gender: Male	**Employer:** Chalmers tekniska högskola

Sjöberg, Jonas 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.