Application

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2015-03871	Giselsson, Pontus	NT-14

Information about applicant

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Information about application

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Descriptive data

Project info

Project title (Swedish)*

Algoritmer och verktyg for parametrisk optimering

Project title (English)*

Algorithms and tools for parametric optimization

Abstract (English)*

Convex optimization is a core technology in many engineering fields. In some fields, the time the optimization algorithm takes to solves the optimization problem is not overly important, while in some fields it is of paramount importance. In this project, we focus on developing state-of-the-art optimization algorithms and software tools for applications where optimization algorithm performance is indeed crucial for applicability. The applications of primary interest to this project are optimization based control, real-time medical (MRI) image reconstruction, and statistical estimation in biology.

The research project is divided into three sub-projects, where the first is to develop algorithms and software for optimization-based control. The limiting factor for applying optimization-based control to systems with fast dynamics is that the inter-sampling time, within which the optimization algorithm must compute a control action to apply, is very short. Thus, to be able to control systems with faster dynamics, faster optimization algorithms are needed. This sub-project will be based on work done by the applicant, in which he has developed state-of-the-art algorithms for optimization-based control. This project will generalize and improve on these ideas.

In the second sub-project, real-time MRI image reconstruction is considered. To optimally reconstruct MRI images, a specific optimization problem is solved. Because of the real-time requirement, these optimization problems must be solved very fast. The objective is to develop optimization algorithms that are efficient enough to achieve this.

As a third driving application for the algorithm development, we have high-dimensional estimation in biology. The objective is to decide which genome variations that are responsible for a certain characteristic in a person. This can be formulated as a large-scale optimization problem. Several similar optimization problems for different persons need to be solved in order to detect the correct variation with statistical certainty. Therefore, it is crucial to have access to efficient large-scale optimization algorithms. The purpose of this sub-project, is to develop such algorithms.

The expected outcome for the research plan is a number of scientific publications as well as state-of-the-art algorithms and tools.

Popular scientific description (Swedish)*

Inom regelteknik är målet att styra dynamiska system, alltså system som hela tiden förändras, så att de beter sig som önskat. Ett exempel som kan förklara hur ett reglertekniskt system fungerar, är fasthållaren i en bil. I farthållaren är målet att hålla en konstant fart. Detta åstadkoms genom att den aktuella farten mäts. Mätningen skickas sedan till en regulator som beräknar hur mycket gas som ska appliceras för att hålla eller uppnå önskad fart. Denna procedur måste upprepas frekvent eftersom bilens fart hela tiden påverkas av yttre faktorer så som backar och vind. En motsvarande övergripande procedur finns i alla reglersystem, den stora skillnaden (förutom att det är olika system som styrs) är hur regulatorn beräknar på vilket sätt systemet ska påverkas. För att nå optimal prestanda på sitt system, så kan regulatorn beräkna hur den ska påverka systemet genom att lösa ett optimeringsproblem. Att lösa sådana kan ta lång tid. Ett av målen med detta forskningsprojekt är att utveckla effektiva metoder för att lösa sådana optimeringsproblem.

Ett annat mål med projektet är att skapa effektivare metoder för bildrekonstruktion i medicinsk bildbehandling, närmare bestämt för magnetröntgenmaskiner. Magnetröntgenmaskiner är mycket bra på att visualisera mjukvävnader i kroppen. Det tar dock ganska lång tid att utföra mätningarna som krävs för att skapa dessa bilder. En metod för att förkorta processen är att låta maskinen ta bilder med lägre kvalitet. Dessa lågkvalitativa bilder kan sedan rekonstrueras av datoralgoritmer som ger tillbaka en bild med mycket högre upplösning. Dessa datoralgoritmer är optimeringsbaserade, så för att få effektiv bildbehandling måste även optimeringsalgoritmerna vara effektiva. Att utvecka sådana effektiva optimeringsalgoritmer är det andra målet med detta forskningsprojekt.

Det tredje målet för detta projekt är att utveckla effektiva metoder och verktyg för statistisk estimering i biologi. Målet med estimeringen är att undersöka vilka delar av en gen som bestämmer vilken karakteristik hos en person. Ett sätt att göra detta är genom att lösa väl formulerade optimeringsproblem. Då mängden data i en persons gener är väldigt stor, blir de resulterande problemen väldigt stora, och därför utmanande att lösa. Målet är att utveckla effektiva algoritmer och verktyg som kan hantera detta.

Project period

Number of project years*

3

Calculated project time*

2016-01-01 - 2018-12-31

Deductible time

Deductible time

Cause	Months

Career age: 28

Career age is a description of the time from your first doctoral degree until the last day of the call. Your career age change if you have deductible time. Your career age is shown in months. For some calls there are restrictions in the career age.

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*

1. Naturvetenskap > 101. Matematik > 10199. Annan matematik
2. Teknik > 211. Annan teknik > 21199. Övrig annan teknik

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

Keyword 1*

Optimization algorithms

Keyword 2*

Real-time applications

Keyword 3*

Parametric programming

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*

No ethical considerations.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

Algorithms and tools for Parametric Optimization

Research program

Pontus Giselsson

1 Purpose and aims

Convex optimization has a wide applicability within various fields such as control, image processing, statistical estimation, and signal processing. The optimization problems range from small-scale (in control) to medium- and large-scale (in image processing and statistical estimation). In many of these applications, sequences of very similar optimization problems are solved. There are often incentives to solve the problems very fast. Sometimes there are timing limits (in, e.g., control) on the execution time of the optimization algorithm. Since much of the problem data is the same between different problems in the sequence, a general formulation for the sequence of problems to be solved can be obtained. Such general problem formulations can be in the form of parametric programs. In a parametric program, the data that is the same for the whole sequence is fixed, while the data that differs between instances are called parameters. By specifying the parameters in the parametric program, a problem instance is obtained. This instance can be solved using standard optimization software. When using standard optimization software, the fact that the optimization problems in the sequence are very similar is not exploited to improve performance. The purpose of this research proposal is to develop algorithms that take advantage of the common structure of parametric programs to improve the performance compared to if the problems are considered non-related. This will lead to faster algorithms which enables for the optimization problem sequences to run at higher rates. In the controls community, similar problem formulations have been investigated for some time. However, the solutions obtained there are usually only applicable to small-scale problems. Therefore they are not readily extendable to other application areas such as real-time image processing or statistical estimation. Besides efficiency of the algorithms, the main focus of this research will be on scalability. We aim for developing parametric optimization algorithms and tools that can solve very large-scale problems much faster than current state-of-the-art methods.

2 Survey of the field

2.1 Convex optimization algorithms

There are three main categories of optimization algorithms, interior point methods, active set methods (of which the well known simplex method is a special case), and first-order methods. Within each of these, the algorithms can be divided into finer sub-categories. In general, interior point methods are considered to be robust algorithms that give roughly the same execution time on problems with similar type and dimension. Also, the local convergence behavior is quadratic. Active set methods are considered less robust, and have a worst-case execution time that is exponential in the dimension. However, in practice they tend to perform much better than the worst-case analysis suggests. A draw-back of both these methods is that a linear equation system needs to be solved in each iteration of the algorithm. This is typically done either by an indirect method such as the conjugate gradient method, or by direct matrix factorization. The indirect method is sensitive to problem scaling. Ill-conditioned problems typically take a long time to converge (the final iterates of interior point methods are typically very ill-conditioned). In the general case, the matrix factorization method grows cubically in the dimension of the problem. Therefore, active set methods and interior point methods does not scale very well. First order methods, on the other hand, usually have very cheap iterates that grow roughly linearly in the number of non-zero data-elements (especially after the first iterate, which might require a matrix factorization that can be reused in subsequent iterations). However, compared to interior point methods and often also active set methods, they require more iterations to converge. For well-conditioned problems, the difference in the number of iterations is often small. Therefore, due to the low iteration cost, first order methods usually perform better than the other methods on well-conditioned problems. This performance advantage becomes bigger as the problem size increases because of the better scalability of the iterates.

The basic ideas and complexity estimates of the discussed algorithms are well documented in a number of different text books. For interior points methods, see [21, 27, 6], for active set methods and the simplex, see [22], for the sub-category gradient methods in first order methods, see [20], and for the sub-category proximal splitting algorithms, see [10, 4].

2.2 Parametric programming

Parametric programming has mostly been researched within the controls community. There are algorithm proposals with associated software that are based on interior point methods [9, 26, 19], (online) active set methods [11], first-order methods [23], as well as explicit parametric programming [5] where the solution of the parametric program is precomputed as a function of the parameters.

Explicit quadratic parametric programming is based on the result that the parameter vector space can be divided into regions, and that a simple linear relationship maps the parameter vector to the solution in that region [5]. To find the solution to an instance with a specific parameter vector reduces to verifying in which region the parameter vector belongs to, and to evaluate the simple linear relationship. The complexity of computing these regions, however, grows exponentially in the problem dimension. Therefore, this approach is restricted to really small-scale problems.

Online active set methods (which they are referred to when solving a sequence of optimization problems) are based on a similar idea as the explicit parametric programming solution. Instead of computing all regions offline before the sequence of problems is solved, the region that the current parameter vector corresponds to is searched for online. When the correct region is found, the solution is computed by solving a linear system. Due to the similarities between problems, the region for the next parameter vector in the sequence is often close to the previous one. Therefore the previous solution can be handed as an initial guess to for the region (or equivalently for the active set) to speed up the search for the current active set in the parametric programming case.

This is exploited in [11] and allows for solving larger parametric programs than in the explicit case.

In interior point methods, the factorization step can be made less expensive in the parametric case. The permutation in the factorizations can be determined offline based on the sparsity structure of the parametric program. The computational effort to decide this permutation is then reduced from the online algorithm. This is exploited in [9, 26] for control purposes (where the control problem structure is further exploited to reduce the full factorization to a number of smaller factorizations) and in [19] for more general problem structures.

In first-order methods, there are several things that can be exploited to improve the performance in the parametric case compare to the standard stand-alone case. One simple thing is to note that the potential factorization often is the same for all problem instances. In such cases, the corresponding matrix factorization can be computed offline to reduce on the online execution time. Especially for large-scale problems where a matrix factorization is very costly, this can improve the online performance considerably. Another thing is to perform preconditioning of the problem data to get a well-conditioned problem on which first order methods typically perform well. To have "well-conditioned data" is typically only defined for problem formulations with strong assumptions (such as smoothness and strong convexity) and it is in e.g. [15, 12] shown how to precondition the problem in such cases. For problems with more general assumptions, it becomes more involved, and the performance of the algorithm will depend on other things as well. In these cases, the convergence behavior and the effect of preconditioning is less well understood. There are some preconditioning heuristics presented in [15, 12] that for some problems achieve good performance. However, a better understanding is needed to develop preconditioning methods that guarantee a well performing algorithm in the general case. A third thing that can be used to improve the performance is, as for the other algorithms, to tailor and generate code for a specific parametric program. When doing so, the compiler can optimize the code extensively, and most data checks can be made offline, before code generation, instead of online.

2.3 Applications of parametric programming

In this section, various applications areas of parametric programming are discussed. We will focus on control, real-time medical imaging, and high-dimensional statistical estimation in biology.

2.3.1 Control

The objective in control is to continuously manipulate a dynamical system (i.e., a system that continually evolves) such that it behaves as desired. For instance, for the cruise control in a car, the objective is to keep the car at a desired speed by controlling the amount of throttle to be applied. The amount to be applied is continuously reevaluated/recomputed since the speed of the car may increase or decrease at any time depending on outside disturbances such as hills and wind. This continuous reevaluation of the amount of throttle to be applied needs information on the current speed (and perhaps past speeds) to make an informed decision on what throttle to apply next. Thus, the speed is continuously (or at least very often) measured, the measurement is sent to the *controller* that computes the amount of throttle to be applied. Then the throttle is applied, whereafter the procedure is repeated with a new measurement of the current speed. This procedure forms a feedback scheme where information from the system to be controlled is continuously fed back to the controller that, in turn, decides how to manipulate the system based on the received information. This feedback procedure is used in all control systems. They differ (essentially) only in how the action to be applied to the system is computed.

Most industrial control systems today use simple computational schemes to decide the control action to be applied. However, recently there has been a great interest in using optimization-based control schemes instead, i.e., control schemes in which the control action is computed by solving an optimization problem. The reason is that this can lead to improved performance for the controlled system, since an optimization problem can well capture limitations and performance objectives, and return the optimal decision to be applied. There is one great challenge that has, up till recently, prevented the use of optimization-based control schemes for fast dynamical systems. It is that there are hard execution time constraints on the solution time of the problem instances in the sequence of problems to be solved. To be able to control dynamical systems that change/evolve fast, these execution time limits are hard to satisfy. Thus, the efficiency of available optimization algorithms play a crucial role in enabling optimization-based control on systems with very fast dynamics. Quite many algorithms has been proposed with this application primarily in mind, see Section 2.2 for details, limitations, and references.

Applications within control that have reasonably fast dynamics and that could benefit from optimization-based control include industrial robotics (for assembly), active safety systems in cars (anti-spin, traction-control, etc), flight control, autonomous vehicles, and plasma control in tokamaks (fusion reactors), to name a few.

2.3.2 Medical imaging

In medical imaging, the objective is to create visual representations/images for the interior of a body. There are different methods to achieve this, with two prominent examples being computerized tomography (CT) and magnetic resonance imaging (MRI). In CT, a series of X-rays are taken from many different angles. The quality of these 2-dimensional X-ray images are then improved using computer algorithms, and 3-dimensional representations of the bone or soft tissue under examination can be constructed from the 2-dimensional images. In MRI, instead of using X-rays, images of the interior of the body are obtained by applying a strong magnetic field around the soft tissue to be examined. This magnetic field aligns almost half of the hydrogen protons in one direction, while the other (almost) half is aligned in the opposite direction. Then a radio-frequency pulse is transmitted towards the area under examination. This radio-frequency pulse excites the small fraction of hydrogen protons that are not aligned in either way. When the radio-frequency signal is later turned off, the hydrogens eventually return to their natural alignment within the magnetic field. When doing so, they transmit a signal that can be detected by the machine and used to create 2-dimensional images of the soft tissue under examination. These 2-dimensional images can then be put together using computer software to give 3-dimensional representations of the soft tissue.

The drawback of CT is that X-rays are used, which are carcinogen. This drawback is not present in MRIs, but in MRIs the image acquisition time is usually rather long which may be uncomfortable for the patient and limits the amount of MRI scans that can be performed during one day. Thus, in both these methods, there is a need to obtain equally high quality images using a smaller dosage of X-rays in CT and shorter scan times in MRI, i.e., using *under-sampled* data. Under certain (sparsity) assumptions, perfect image reconstruction can be achieved with very high probability from under-sampled data by solving a specific convex optimization problem (this is an application of compressed sensing, which formulates the optimization problem to be solved to reconstruct a signal (image) from under-sampled data, see [8]). Thus, optimization algorithms play a central role in making CT scans less unhealthy and MRI scans less time consuming. Since parts of the optimization data is the same between consecutive images, the reconstruction problem can be cast as a parametric program. This can be exploited to develop highly efficient algorithms. This is needed to be able to monitor in real-time the patient under observation, because of the hard execution time constraints. The time for image acquisition plus the time for image reconstruction must be less than 20-40 ms to get an update frequency of 25-50 Hz (which is required to get a smooth playback). This is quite challenging, and not achievable by today's methods without introducing approximations and simplifications, see [18, 25], or by using filtering techniques instead of optimization-based techniques as in [24].

2.3.3 High-dimensional statistical estimation in biology

Modern biology centers more and more on information of very high dimension, see, e.g., [7]. New techniques have made it possible to cheaply and fast sequence the whole genome of an organism, leading to a revolution in the way biological and medical research is done. For instance, an important topic in modern biology is genome wide association studies; the collection of associations between small mutations in the human genome and behaviors and characteristics among individuals, something that was impossible to imagine just fifteen years ago. The associations are found by correlating all small variations in the genome of a population with for instance, in the case of a disease, case and control patients. In the case of a human, millions of these genotypic variations exist and need to be tested for an exhaustive evaluation of how the genome affects the characteristics of the person. Almost all of the variation is expected to have no influence over the characteristic. Thus, the statistical problem has a very sparse structure. To find the significant genome variations for a certain characteristic, i.e. increased probability to develop a certain disease, can be cast as a large-scale and sparse convex optimization problem. Ideally, the problem should be solved for a number of parameter values to find the optimal configuration to determine which genotypic variations that really influence the characteristic. Also, to get an estimate of the uncertainty and significance of the results, a huge number of problems - with a similar problem structure - needs to be solved. Therefore, this can be cast as a (large-scale and sparse) parametric program. To develop highly efficient algorithms and tools for this is highly anticipated to reduce the time needed to find the influential genotype variations for a certain characteristic. Today, tools that solve such large-scale parametric problems efficiently are scarce with prominent exceptions for large-scale statistical estimation being, e.g., [28, 1].

3 Project description

The main focus of this research proposal is on developing efficient optimization algorithms and creating software for convex parametric programs. Special focus will be on scalability of the algorithms to enable efficient large-scale parametric programming. This focus on scalability, leads us to consider first-order optimization methods. The main theoretical considerations will be on preconditioning techniques for these first order methods to give them a robust performance. There are already some results available (from the applicant and others as discussed in Section 2.2) that provide optimal preconditioning techniques for a limited class of problems and heuristic preconditioning methods for a bigger class of problems. These methods, however, do not always work well. To further understand the convergence properties in the general case will be of importance when developing new preconditioning techniques.

Another outcome of this project is optimization software for parametric programming. There will be several different software packages. One package is QPgen. An initial release of QPgen is already available. The plan is to extend this in several directions to improve performance and increase applicability, e.g., to make QPgen applicable to a wider class of problems. Currently QPgen targets standard single core computers with floating-point arithmetics. The plan is to develop parallel versions of QPgen since the underlying algorithms are suitable for parallelization. We will target standard multi-core CPUs, GPUs, as well as FPGAs with fixed-point arithmetics. The latter of these projects is an ongoing collaboration with (parts of) the Circuits and Systems Group at Imperial College in London. Since QPgen already shows state-of-the-art performance (see Section 5) this will further position QPgen as a leading software for parametric programming (especially for large-scale problems).

Another software package that will result from this research proposal is a parametric mixed-integer quadratic programming solver. These algorithms are often based on branch-and-bound. In branch-and-bound, several standard quadratic programming problems are solved to compute upper and lower bounds on the optimal value of the mixed integer problem. These quadratic programming problems have a similar structure, and they can be seen as instances of a parametric program. Therefore QPgen is well suited as an internal quadratic programming solver for the branch-and-bound algorithm. The main theoretical focus in this sub-project is research how to exploit the parametric structure of the problem in the branch-and-bound algorithm. Software-wise, the target is to develop a library free MIQP solver written in C that can be used in embedded applications. The main motivation behind developing this tool comes from optimization based control of hybrid systems. Initial steps in this work is currently taken in a Master Thesis project conducted under the the applicant's supervision.

Image reconstruction in MRIs typically involve wavelet transform operators as opposed to matrix data. The first-order methods can typically cope with this, but different preconditioning techniques are needed. The intention is to develop such preconditioning techniques and the goal is to implement a demonstration that achieves real-time image-reconstruction.

We will also develop novel methods and tools for high dimensional statistical estimation in biology. Below is a time line and work-load division for the different sub-project outlined above.

- The theoretical considerations regarding preconditioning will follow through the full research period. This will be an area where the applicant is actively involved.

- Development of QPgen and the parametric MIQP solver will be undertaken by Master Thesis students and/or a PhD-student in his/her early years. The applicant will support as adviser. This is expected to be finished by the end of 2016.

- The ongoing project to make QPgen support code generation to, e.g., FPGAs with fixed-point arithmetics is undertaken by the research group at Imperial College with support from the applicant and possibly a local PhD student. There are several theoretical considerations that need to be resolved before a reliable fixed-point implementation can be achieved. This project is expected to last until the summer of 2017.

- The application on real-time medical imaging will be the work of future Master Thesis and/or PhD students with supervision by the applicant. This work will start later in 2016 and run throughout the research plan period.
- The project on high-dimensional statistical estimation will be joint work with a PhD student already employed at the Department of Automatic Control in Lund who returns from his visit at the Pasteur Institute in Paris in the spring of 2015. A collaboration to develop highly efficient parametric optimization methods for high-dimensional statistical estimation in biology will then start. This collaboration is expected to be ongoing throughout the research period and the applicant is expected to contribute actively.

4 Significance

It is expected that the project will contribute to theoretical understanding of first order optimization algorithms and the effect of preconditioning on performance. This will enable for constructing faster algorithms that, in turn, give a wider applicability for optimization based ideas in different fields. In control, it is expected that faster systems with larger dimension can be controlled using optimization-based control. In MRI-imaging, it is expected that real-time optimization based reconstruction is achieved (which it is not today). It is also expected that the algorithms will decrease significantly the waiting time for analysts when solving high-dimensional statistical estimation problems in biology (and elsewhere).

5 Preliminary results

The research recently and currently pursued by the applicant is focused on developing highly tailored optimization algorithms and software for parametric programming. This research proposal is a continuation of these ideas. The work already performed by the applicant shows very promising performance. The main theoretical advances are reported in [13, 14, 17, 16]. These concern preconditioning for first order methods and other ways to improve the convergence. These findings form the basis for the initial release of the QPgen solver [2].

The QPgen solver shows very promising performance. In Table 1, QPgen is compared to the interior point method in FORCES [9], the online active set method qpOASES proposed in [11], the explicit parametric solver MPT toolbox with theoretical foundations in [5], and to MOSEK [3] which is a state-of-the-art commercial solver for standard (non-parametric) optimization. The results reported in the left table in Table 1 are obtained by solving a small-scale control problem (with approximately 60 decision variables). We see that the performance of QPgen is better than the performance of FORCES, qpOASES, and MOSEK. Despite that the problem is very small-scale, it is too large for explicit parametric programming in the MPT toolbox, which is therefore omitted from the table. The performance improvement, however, is not vast. In the right table in Table 1, results are reported for when solving sparse parametric lasso problems (that arise in both MRI image reconstruction and statistical estimation) with 10’000 variables using QPgen and MOSEK (the other methods have no performance results since they are either incompatible with problem type or problem size, and are therefore omitted from the comparison). We see that QPgen

Table 1: Algorithm performance comparison for small-scale control problem (left) and medium-scale estimation problem (right).

	execution time	
solver	avg. (ms)	max. (ms)
QPgen	0.098	0.26
FORCES	0.347	0.592
qpOASES	0.189	5.8
MOSEK	4.6	8.1

	exec time (ms)	
	avg.	max
QPgen	38.1 ms	48.1 ms
MOSEK	824.3 s	894.5 s

is more than 20'000 times faster than MOSEK for these problems. This improvement factor is further increased as the problem size increases.

6 Independent line of research

The applicant performed his PhD studies at the Department of Automatic Control under the supervision of Prof. Anders Rantzer. The applicant's PhD work originated from a distributed optimization based control idea from his adviser Prof. Anders Rantzer. As the PhD studies went on, the applicants research interest steered more towards optimization than control (which was the original focus). Since optimization is not an area of primary expertise of the applicants PhD adviser, much of this work was made independently by the applicant. That the applicant did carve his own research path during his PhD studies is documented by the many papers he has written as a sole author. Also, the success along this path is documented by the various best paper (finalist) awards he has been honored with for work pursued during (and after) his PhD studies.

Shortly after PhD graduation, the applicant moved to Stanford University for postdoctoral studies. At Stanford, the applicant had the great honor to be working with one of the most well known researchers within the field of optimization, namely Prof. Stephen Boyd. During the applicant's postdoctoral studies at Stanford, his knowledge in optimization became deeper and wider. The research pursued by the applicant at Stanford followed the track initiated by him during the late phase of his PhD studies, namely preconditioning methods for first-order optimization algorithms in parametric programming. This particular area of optimization was (or is) not an active area of research in Prof. Boyd's group at Stanford. It was initiated by the applicant, which further confirms his independence as a researcher.

7 Employment

The project leader Pontus Giselsson is since Jan 1, 2015 an Assistant Professor at the Department of Automatic Control at Lund University. The position is limited to four years with possibilities to apply for a permanent Associate Professor position before the end of this four year period.

8 Other grants

The applicant has applied for funding from the Swedish Foundation for Strategic Research. It covers one PhD student for 3 years. A decision is yet to be taken (probably early April 2015). The workload for the proposed project is too much for a single PhD student. Therefore this proposal is also submitted.

References

[1] EstimateS. Online: http://viceroy.eeb.uconn.edu/estimates/.

[2] QPgen: A C code generator for quadratic optimization problems. http://www.control.lth.se/user/pontus.giselsson/qpgen/.

[3] Mosek ApS. Optimization software. http://www.mosek.com/.

[4] H. H. Bauschke and P. L. Combettes. *Convex Analysis and Monotone Operator Theory in Hilbert Spaces*. Springer, 2011.

[5] A. Bemporad, M. Morari, V. Dua, and E.N. Pistikopoulos. The explicit linear quadratic regulator for constrained systems. *Automatica*, 38(1):3–20, January 2002.

[6] S. Boyd and L. Vandenberghe. *Convex Optimization*. Cambridge University Press, New York, NY, 2004.

[7] P. Bühlmann, M. Kalisch, and L. Meier. High-dimensional statistics with a view toward applications in biology. *Annual Review of Statistics and Its Application*, 1(1):255–278, 2014.

[8] E. J. Candes, J. Romberg, and T. Tao. Robust uncertainty principles: exact signal reconstruction from highly incomplete frequency information. *IEEE Transactions on Information Theory*, 52(2):489–509, Feb 2006.

[9] A. Domahidi, A. Zgraggen, M.N. Zeilinger, M. Morari, and C.N. Jones. Efficient interior point methods for multistage problems arising in receding horizon control. In *51st IEEE Conference on Decision and Control*, pages 668–674, Maui, HI, USA, December 2012.

[10] J. Eckstein. *Splitting methods for monotone operators with applications to parallel optimization*. PhD thesis, MIT, 1989.

[11] H. J. Ferreau, H. G. Bock, and M. Diehl. An online active set strategy to overcome the limitations of explicit mpc. *International Journal of Robust and Nonlinear Control*, 18(8):816–830, 2008.

[12] E. Ghadimi, A. Teixeira, I. Shames, and M. Johansson. Optimal parameter selection for the alternating direction method of multipliers (ADMM): Quadratic problems. 2013. Submitted. Available: http://arxiv.org/abs/1306.2454.

[13] P. Giselsson. Improved fast dual gradient methods for embedded model predictive control. In *Proceedings of 2014 IFAC World Congress*, pages 2303–2309, Cape Town, South Africa, August 2014.

[14] P. Giselsson and S. Boyd. Diagonal scaling in Douglas-Rachford splitting and ADMM. In *53rd IEEE Conference on Decision and Control*, pages 5033–5039, Los Angeles, CA, December 2014.

[15] P. Giselsson and S. Boyd. Metric selection in Douglas-Rachford splitting and ADMM. 2014. Submitted. Available: `http://arxiv.org/abs/1410.8479`.

[16] P. Giselsson and S. Boyd. Metric selection in fast dual gradient methods. 2014. Submitted.

[17] P. Giselsson and S. Boyd. Monotonicity and restart in fast gradient methods. In *53rd IEEE Conference on Decision and Control*, pages 5058–5063, Los Angeles, CA, December 2014.

[18] A Majumdar, R.K. Ward, and T. Aboulnasr. Compressed sensing based real-time dynamic MRI reconstruction. *IEEE Transactions on Medical Imaging*, 31(12):2253–2266, Dec 2012.

[19] J. Mattingley and S. Boyd. Cvxgen: a code generator for embedded convex optimization. *Optimization and Engineering*, 13(1):1–27, 2012.

[20] Y. Nesterov. *Introductory Lectures on Convex Optimization: A Basic Course*. Springer Netherlands, 1st edition, 2003.

[21] Y. Nesterov and A. Nemirovskii. *Interior-Point Polynomial Algorithms in Convex Programming*. Society for Industrial and Applied Mathematics, 1994.

[22] J. Nocedal and S. Wright. *Numerical optimization*. Springer series in operations research and financial engineering. Springer, New York, NY, 2nd edition, 2006.

[23] S. Richter. *Computational Complexity Certification of Gradient Methods for Real-Time Model Predictive Control*. PhD thesis, ETH, Zurich, Switzerland, November 2012.

[24] U. Sumbul, J. M. Santos, and J. M. Pauly. A practical acceleration algorithm for real-time imaging. *IEEE Transactions on Medical Imaging*, 28(12):2042–2051, Dec 2009.

[25] M. Uecker, S. Zhang, D. Voit, A. Karaus, K.-D. Merboldt, and J. Frahm. Real-time MRI at a resolution of 20 ms. *NMR in Biomedicine*, 23(8):986–994, 2010.

[26] Y. Wang and S. Boyd. Fast model predictive control using online optimization. *IEEE Transactions on Control Systems Technology*, 18(2):267–278, March 2010.

[27] S. Wright. *Primal-Dual Interior-Point Methods*. Society for Industrial and Applied Mathematics, 1997.

[28] T. Zhao, H. Liu, K. Roeder, J. Lafferty, and L. Wasserman. The huge package for high-dimensional undirected graph estimation in R. *J. Mach. Learn. Res.*, 13:1059–1062, 2012.

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

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	Pontus Giselsson	25
2	PhD Student		80
3	PhD Student		40

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	Total
1	Applicant	Pontus Giselsson	25	207,000	213,210	219,606	639,816
2	PhD Student		80	417,600	430,128	443,032	1,290,760
3	PhD Student		40	208,800	215,064	221,515	645,379
	Total			833,400	858,402	884,153	2,575,955

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

Running Costs

	Running Cost	Description	2016	2017	2018	Total
1	Resekostnader	Conferences, workshops, longer reaseach visits	200,000	200,000	200,000	600,000
	Total		200,000	200,000	200,000	600,000

Depreciation costs

Depreciation cost	Description	2016	2017	2018

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	Total, applied	Other costs	Total cost
Salaries including social fees	833,400	858,402	884,153	2,575,955		2,575,955
Running costs	200,000	200,000	200,000	600,000		600,000
Depreciation costs				0		0
Premises				0		0
Subtotal	1,033,400	1,058,402	1,084,153	3,175,955	0	3,175,955
Indirect costs	30,000	30,000	30,000	90,000		90,000
Total project cost	1,063,400	1,088,402	1,114,153	3,265,955	0	3,265,955

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

Bidrag sökes för 25 % av sökandes lön samt 80 % av en doktorands lön och 40 % av en annan doktorandlön för hela perioden. En annan projektansökan för ett liknande projekt är också inskickad till SSF som finansierar ca 1.5 doktorander. Arbetsmängden i de föreslagna projekten motsvarar ca tre doktoranders jobb. Därför är även denna ansökan inskickad.

Dessutom sökes bidrag för resekostnader i samband med konferenser, längre forskningsbesök utomlands, samt workshops. Doktoranderna åker typiskt på två konferenser per år, och handledaren åker typiskt på två till fyra. Dessutom finns det lite marginal för att bjuda in, eller åka och besöka internationella forskare. Dessa utgiftsposter är lagda under driftskostnader.

Under indirekta kostnader finns poster som ska täcka laptops och annan datautrustning som behövs för projektet.

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	Total
1	SSF	Pontus Giselsson	Ingvar Carlsson Award (beslut ej taget)	ICA140050	1,080,000	1,355,000	1,225,000	3,660,000
	Total				1,080,000	1,355,000	1,225,000	3,660,000

CV and publications

CV

PONTUS GISELSSON

Näktergalsvägen 20 Phone: +46 733 610053
SE-24736 Södra Sandby, Sweden Email: pontus.giselsson@control.lth.se
http://control.lth.se/Staff/PontusGiselsson.html

1. HIGHER EDUCATION DEGREE

Lund Institute of Technology - *M.Sc. Physical Engineering* Graduated Oct. 2006
Focus on Automatic Control.

2. DOCTORAL DEGREE

Lund Institute of Technology - *Ph.D. Automatic Control* Graduated Nov. 2012
Focus on algorithms for large-scale optimization problems and stability theory for distributed model predictive control. Thesis title is *Gradient-Based Distributed Model Predictive Control*. Advised by Anders Rantzer.

3. POSTDOCTORAL POSITIONS

Stanford university - *Postdoc* Sep. 2013 – Dec. 2014
Advised by Prof. Stephen Boyd.

Lund Institute of Technology - *Postdoc* Jan. 2013 - Feb. 2013
Advised by Prof. Anders Rantzer. June 2013 - Aug. 2013

5. CURRENT POSITION

Lund Institute of Technology - *Assistant Professor* Jan. 2015 -
Lecturer and course responsible for undergraduate courses Systems Engineering and Process Control.
0 % research. Temporary position.

6. PREVIOUS (ACADEMIC) POSITIONS AND PERIODS OF APPOINTMENT

Lund Institute of Technology - *Assistant Professor* Mar. 2013 - May 2013
Lecturer and course responsible for undergraduate courses Systems Engineering and Process Control.

9. AWARDS AND HONORS

Young Author Price at the *19th IFAC World Congress* August 2014
Sole author of the award winning paper.

Young Author Price finalist at the *19th IFAC World Congress* August 2014
Sole author of two out of five finalist papers for the young author price (one of which won, see above).

Best Student Paper Award finalist at *2013 American Control Conference* June 2013
One out of five finalists for the best student paper award at 2013 American control conference.

Young Author Price at *8th IFAC International Symposium on Advanced Control of Chemical Processes* July 2012
Co-author with fellow Ph.D. student from Lund Institute of Technology of paper that was awarded Young author price.

9. INVITED TALKS (except conference publication presentations)

Modelon, Lund, Sweden Apr. 2, 2015

IMT Lucca, Lucca, Italy Sept.8, 2014
Two-day workshop on *Embedded Optimization*

San Diego, California, USA May 21, 2014
Three day conference on Optimization

Kassel University, Kassel, Germany — Jan. 8, 2014
Two-day workshop on *Distributed and Cooperative Control of Networked Systems*

IMT Lucca, Lucca, Italy — May 29, 2013
At the Dynamical Systems, Control, and Optimization group

EPFL, Lausanne, Switzerland — May 21, 2013
At the Automatic Control Laboratory

Linköping University, Linköping, Sweden — Feb. 28, 2013
At the Department of Electrical Engineering

9. Master Thesis Supervision

Optimization tool development for MIQP problems arising in hybrid control — ongoing
Lucas Jimbergsson and Mattias Fält
Primary adviser

Development of a solution for start-up optimization of a thermal power plant — ongoing
Marcus Andrén and Christoffer Wedding
Secondary adviser

District heating optimization — ongoing
Henning Larsson
Secondary adviser

Cooperative adaptive cruise control — ongoing
John Wahnström
Secondary adviser

Model Predictive Control for Stock Portfolio Selection — Sep. 2009 - Feb. 2010
Anneli Ögren and Sara Alenmyr
Primary adviser

9. International Collaboration

Hosted Ph.D. student **Minh Dang Doan** from *TU Delft*, Delft, the Netherlands — Apr. 1, 2011 - June 18, 2011
Collaboration resulted in two published journal articles.

Publication list

Publication list

The five most important works are marked with a ⋆. All publications are available via my homepage `http://control.lth.se/Staff/PontusGiselsson.html`.

1. Peer-reviewed articles

[1] M. D. Doan, P. Giselsson, T. Keviczky, B. De Schutter, and A. Rantzer. A distributed accelerated gradient algorithm for distributed model predictive control of a hydro power valley. *Control Engineering Practice*, 21(11):1594–1605, 2013.

[2] P. Giselsson, M. D. Doan, T. Keviczky, B. De Schutter, and A. Rantzer. Accelerated gradient methods and dual decomposition in distributed model predictive control. *Automatica*, 49(3):829–833, 2013.

[3] ⋆P. Giselsson and A. Rantzer. On feasibility, stability and performance in distributed model predictive control. *IEEE Transactions on Automatic Control*, 59(4):1031–1036, April 2014.

[4] A. Lindholm and P. Giselsson. Minimization of economical losses due to utility disturbances in the process industry. *Journal of Process Control*, 2013. Accepted for publication.

2. Peer-reviewed conference contributions

[5] P. Giselsson. Adaptive nonlinear model predictive control with suboptimality and stability guarantees. In *Proceedings of the 49th Conference on Decision and Control*, pages 3644–3649, Atlanta, GA, December 2010.

[6] P. Giselsson. Model predictive control in a pendulum system. In *Proceedings of the 31st IASTED conference on Modelling, Identification and Control*, Innsbruck, Austria, February 2011.

[7] P. Giselsson. Execution time certification for gradient-based optimization in model predictive control. In *Proceedings of the 51st IEEE Conference on Decision and Control*, pages 3165–3170, Maui, HI, December 2012.

[8] P. Giselsson. A generalized distributed accelerated gradient method for DMPC with iteration complexity bounds. In *Proceedings of 2013 American Control Conference*, Washington D.C., June 2013. Accepted for publication.

[9] P. Giselsson. Optimal preconditioning and iteration complexity bounds for gradient-based optimization in model predictive control. In *Proceedings of 2013 American Control Conference*, Washington D.C., June 2013. Accepted for publication.

[10] P. Giselsson. Output feedback distributed model predictive control with inherent robustness properties. In *Proceedings of 2013 American Control Conference*, Washington D.C., June 2013. Accepted for publication.

[11] P. Giselsson. Improved dual decomposition for distributed model predictive control. In *Proceedings of 2014 IFAC World Congress*, pages 1203–1209, Cape Town, South Africa, August 2014.

[12] P. Giselsson, J. Åkesson, and A. Robertsson. Optimization of a pendulum system using Optimica and Modelica. In *Proceedings of the 7th International Modelica Conference 2009*, pages 480–489, Como, Italy, September 2009.

[13] P. Giselsson and S. Boyd. Preconditioning in fast dual gradient methods. In *Proceedings of the 53rd Conference on Decision and Control*, pages 5040–5045, Los Angeles, CA, December 2014.

[14] P. Giselsson and A. Rantzer. Distributed model predictive control with suboptimality and stability guarantees. In *Proceedings of the 49th Conference on Decision and Control*, pages 7272–7277, Atlanta, GA, December 2010.

[15] ⋆P. Giselsson. Improved fast dual gradient methods for embedded model predictive control. In *Proceedings of 2014 IFAC World Congress*, pages 2303–2309, Cape Town, South Africa, August 2014.

[16] ⋆P. Giselsson and S. Boyd. Diagonal scaling in Douglas-Rachford splitting and ADMM. In *53rd IEEE Conference on Decision and Control*, pages 5033–5039, Los Angeles, CA, December 2014.

[17] ⋆P. Giselsson and S. Boyd. Monotonicity and restart in fast gradient methods. In *53rd IEEE Conference on Decision and Control*, pages 5058–5063, Los Angeles, CA, December 2014.

[18] A. Lindholm and P. Giselsson. Formulating an optimization problem for minimization of losses due to utilities. In *8th IFAC International Symposium on Advanced Control of Chemical Processes*, Singapore, July 2012.

[19] A. Lindholm, P. Giselsson, N-H. Quttineh, C. Johnsson, H. Lidestam, and K. Forsman. Production scheduling in the process industry. In *Proceedings of the 22nd International Conference on Production Research*, Iguassu Falls, Brazil, July 2013. Accepted for publication.

[20] J. M. Maestre, P. Giselsson, and A. Rantzer. Distributed receding horizon Kalman filter. In *Proceedings of the 49th Conference on Decision and Control*, pages 5068–5073, Atlanta, GA, December 2010.

5. Books and book chapters

[21] P. Giselsson and A. Rantzer. Generalized accelerated gradient methods for DMPC based on dual decomposition. In R. R. Negenborn and J. M. Maestre, editors, *Distributed MPC made easy*. Springer, 2013.

7. Computer Programs

[22] ⋆P. Giselsson. QPgen: A C code generator for quadratic optimization problems. Available: `http://www.control.lth.se/user/pontus.giselsson/qpgen`, 2014.

CV

Name: Pontus Giselsson	**Doctorial degree:** 2012-11-23
Birthdate: 19800310	**Academic title:** Doktor
Gender: Male	**Employer:** No current employer

Research education

Dissertation title (swe)

Dissertation title (en)

Gradient-Based Distributed Model Predictive Control

Organisation	Unit	Supervisor
Lunds universitet, Sweden Sweden - Higher education Institutes	Reglerteknik 107161	Anders Rantzer

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
21199. Övrig annan teknik	0280-5316	2012-11-23

Publications

Name: Pontus Giselsson	**Doctorial degree:** 2012-11-23
Birthdate: 19800310	**Academic title:** Doktor
Gender: Male	**Employer:** No current employer

Giselsson, Pontus 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.