Congnitive Science Laboratory

Shuxue Ding
Professor

Taro Suzuki
Senior Associate Professor

The research and education activities in the laboratory focus on the cognitive science, computation and engineering, including broad applications of them. Our work covers Statistical signal processing, Neuro-Computing, Brain style signal processing and informatics, Multi-in and multi-out system (MIMO system), Information theory, Swarm intelligence, Machine learning, Optimization, Simulated acoustics, XML Transformation, Functional Logic Programming, Term Rewriting Systems, Program Transformation and related topics.

Areas of research interest include

- Sparse representation and sparse component analysis;
- Compressive sensing or sampling;
- Digital and statistical signal processing;
- Blind source separation and independent component analysis, and their applications in acoustic signals and vital signs;
- Neural computing and brain-style signal processing;
- Machine learning and optimization;
- Time-reversal wave propagation in ergodic environment and its applications in acoustics, ultrasonics and telecommunications;
- Application of logic, category theory, coinduction to computer science;
- Semantics, verification and implementation of functional reactive programming languages;

- Application of (functional) reactive programming in real-world problems such as robotics, embedded systems and network infrastructures;
- Program verification with interactive theorem provers;
- Theory and implementation of interactive theorem provers;
- Semantics and verification of hardware specification languages;
- Algorithms for efficient pattern matching based on finite automata;
- Semantics and verification of XML document transformation;
- Information theory and algorithmic complexity.
- Mechanical signal analysis with sparse representation approach
- Composites damage detection with signal processing method
- Structural health monitoring based on Lamb waves
- Non-destructive evaluation for thin-wall structures

Faculties of the Cognitive Science laboratory teach Algorithms and Data Structures, Digital Signal Processing, Introduction to Topology, Automata and Languages, Language Processing Systems, Computer Languages, Statistical Signal Processing (graduate course), Computation Theory (graduate course), Declarative Programming (graduate course), SCCPs and other selective courses. Students join faculty research and also develop their own research themes.

Refereed academic journal

[sding-106-005-01:2015] Yujie Li, Shuxue Ding, and Zhenni Li. Dictionary learning with the cosparse analysis model based on summation of blocked determinants as the sparseness measure. *Digital Signal Processing (Elsevier)*, 48(10):298–309, Oct. 2015.

Dictionary learning is crucially important for sparse representation of signals. Most existing methods are based on the so called synthesis model, in which the dictionary is column redundant. This paper addresses the dictionary learning and sparse representation with the so-called analysis model. In this model, the analysis dictionary multiplying the signal can lead to a sparse outcome. Though it has been studied in the literature, there is still not an investigation in the context of dictionary learning for nonnegative signal representation, while the algorithms designed for general signal are found not sufficient when applied to the nonnegative signals. In this paper, for a more efficient dictionary learning, we propose a novel cost function that is termed as the summation of blocked determinants measure of sparseness (SBDMS). Based on this measure, a new analysis sparse model is derived, and an iterative sparseness maximization scheme is proposed to solve this model. In the scheme, the analysis sparse representation problem can be cast into row-to-row optimizations with respect to the analysis dictionary, and then the quadratic programming (QP) technique is used to optimize each row. Therefore, we present an algorithm for the dictionary learning and sparse representation for nonnegative signals. Numerical experiments on recovery of analysis dictionary show the effectiveness of the proposed method.

[sding-106-005-02:2015] Pingmei Caia, Guinan Wanga, Hongjuan Zhang, Shuxue Ding, and Zikai Wu. Sparse Electrocardiogram Signals Recovery Based on Solving a Row Echelon-Like Form of System. *IET Systems Biology*, 10(1):34–40, Feb. 2016.

The study of biology and medicine in a noise environment is an evolving direction in biological data analysis. Among these studies, analysis of electrocardiogram (ECG) signals in a noise environment is a challenging direction in personalized medicine. Due to its periodic characteristic, ECG signal can be roughly regarded as sparse biomedical signals. This study proposes a two-stage recovery algorithm for sparse biomedical signals in time domain. In the first stage, the concentration subspaces are found in advance. Then by exploiting these subspaces, the mixing matrix is estimated accurately. In the second

stage, based on the number of active sources at each time point, the time points are divided into different layers. Next, by constructing some transformation matrices, these time points form a row echelon-like system. After that, the sources at each layer can be solved out explicitly by corresponding matrix operations. It is noting that all these operations are conducted under a weak sparse condition that the number of active sources is less than the number of observations. Experimental results show that the proposed method has a better performance for sparse ECG signal recovery problem.

[sding-106-005-03:2015] Zhenni Li, Shuxue Ding, and Yujie Li. A Fast Algorithm for Learning Overcomplete Dictionary for Sparse Representation Based on Proximal Operators. *Neural computation*, 27:1951–1982, Sept. 2015.

We present a fast, efficient algorithm for learning an overcomplete dictionary for sparse representation of signals. The whole problem is considered as a minimization of the approximation error function with a coherence penalty for the dictionary atoms and with the sparsity regularization of the coefficient matrix. Because the problem is nonconvex and nonsmooth, this minimization problem cannot be solved efficiently by an ordinary optimization method. We propose a decomposition scheme and an alternating optimization that can turn the problem into a set of minimizations of piecewise quadratic and univariate subproblems, each of which is a single variable vector problem, of either one dictionary atom or one coefficient vector. Although the subproblems are still nonsmooth, remarkably they become much simpler so that we can find a closed-form solution by introducing a proximal operator. This leads to an efficient algorithm for sparse representation. To our knowledge, applying the proximal operator to the problem with an incoherence term and obtaining the optimal dictionary atoms in closed form with a proximal operator technique have not previously been studied. The main advantages of the proposed algorithm are that, as suggested by our analysis and simulation study, it has lower computational complexity and a higher convergence rate than state-of-the-art algorithms. In addition, for real applications, it shows good performance and significant reductions in computational time.

[sding-106-005-04:2015] Yujie Li, Shuxue Ding, Zhenni Li, and Wuhui Chen. Nonnegative Dictionary-Learning Algorithm Based on L1 Norm with the Sparse Analysis Model. *Information Engineering Express*, 1(4):1–10, Oct 2015.

Sparse representation has been proven to be a powerful tool for analysis and processing of signals and images. Most of existing methods for sparse repre-

sentation are based on the synthesis model. This paper presents a method for dictionary learning and sparse representation with the so-called analysis model. Different from the synthesis sparse model, in this analysis model, the analysis dictionary multiplying the signal can lead to a sparse outcome. The analysis dictionary learning problem has received less attention with and only a few algorithms has been proposed recently. What is more, there have still been few investigations in the context of dictionary learning for nonnegative signal representation. So, in this paper we focus on the nonnegative dictionary learning for signal representation. We use l_1-norm as the sparsity measure to learn an analysis dictionary from signals in analysis sparse model. In addition, we adopt the Euclidean distance as the error measure in the formulation. Numerical experiments on recovery of analysis dictionary show that the proposed analysis dictionary learning algorithm performs well for nonnegative signal representation.

Refereed proceedings of an academic conference

[sding-106-005-05:2015] Yujie Li, Shuxue Ding, and Zhenni Li. Analysis Dictionary Learning Based on Summation of Blocked Determinants Measure of Sparseness. In *Proc. 2015 IEEE International Conference on Digital Signal Processing (DSP 2015, July 21-24, 2015 in Singapore)*, pages 224–228, Jul. 2015.

(Best Paper Award) This paper addresses the dictionary learning and sparse representation with the analysis model. Though it has been studied in the literature, there is still not an investigation in the context of dictionary learning for nonnegative signal representation. For measuring the sparseness, in this paper, we propose a measure that is so called the summation of blocked determinants. Based on this measure, a new analysis sparse model is derived, and an iterative sparseness maximization approach is proposed to solve this model. In the approach, the nonnegative sparse representation problem can be cast into row-to-row optimizations with respect to the dictionary, and then the quadratic programming (QP) technique is used to optimize each row. Numerical experiments on recovery of analysis dictionary show the effectiveness of the proposed algorithm.

[sding-106-005-06:2015] Zhenni Li, Shuxue Ding, Yujie Li, and Wuhui Chen. Dictionary Learning with $l_{1/2}$ Regularizer for Sparsity Based on Proximal

Operator. In *Proc. IEEE International Conference on Awareness Science and Technology (iCAST 2015, Qinhuagndao, China, Sept. 22-24, 2015)*, pages 105–110, Sept. 2015.

(Best Student Paper Award) In this study, we propose a fast and efficient algorithm for learning overcomplete dictionary for sparse representation of signals using the nonconvex $l_{1/2}$ regularizer for sparsity. The special importance of $l_{1/2}$ regularizer has been recognized in recent studies on sparse modeling. The $l_{1/2}$-norm, however, leads to a nonconvex and nonsmooth optimization problem that is difficult to solve efficiently. In this paper, we propose a method based on a decomposition scheme and alternating optimization that can turn the whole problem into a set of subminimizations of univariate functions, each of which is dependent on only one dictionary atom or the coefficient vector. Although the subproblem with respect to the coefficient vector is still nonsmooth and nonconvex due to the $l_{1/2}$ regularizer, remarkably, it becomes much simpler and it has a closed-form solution by introducing a technique that is proximal operator. The main advantages of the proposed algorithm is that, as suggested by the simulation study, it is faster and more efficient than state-of-the-art algorithms with different sparsity constraints.

[sding-106-005-07:2015] Zhenni Li, Shuxue Ding, and Yujie Li. Dictionary Learning with Log-regularizer for Sparse Representation. In *Proc. 2015 IEEE International Conference on Digital Signal Processing (DSP 2015, July 21-24, 2015 in Singapore)*, pages 609–613, 2015.

We propose a fast and efficient algorithm for learning overcomplete dictionary for sparse representation of signals using the nonconvex log-regularizer for sparsity. The special importance of log-regularizer has been recognized in recent studies on sparse modeling. The log-regularizer, however, leads to a nonconvex and nonsmooth optimization problem that is difficult to solve efficiently. In this paper, We propose a method based on a decomposition scheme and alternating optimization that can turn the whole problem into a set of subminimizations of univariate functions, each of which is dependent on only one dictionary atom or the coefficient vector. Although the subproblem with respects to the coefficient vector is still nonsmooth and nonconvex, remarkably, it becomes much simpler and it has a closed-form solution by introducing a novel technique that is log-thresholding operator. The main advantages of the proposed algorithm is that, as suggested by our analysis and simulation study, it is more efficient than state-of-the-art algorithms with different sparsity constraints.

[sding-106-005-08:2015] Yujie Li, Shuxue Ding, Zhenni Li, and Wuhui Chen. Nonnegative Dictionary-Learning Algorithm for the analysis model based on L1 norm. In *Proc. 4th International Congress on Advanced Applied Informatics (IIAI-AAI-ICSCAI-2015, July 12-16, 2015, Okayama, Japan)*, pages 495–499, 2015.

Sparse representation of signals has been successfully applied in signal processing. Most of existing methods for sparse representation are based on the synthesis model, in which the dictionary is overcomplete. This paper addresses the dictionary learning and sparse representation with the so-called analysis model. Based on this model, the analysis dictionary multiplying the signals can lead to a sparse outcome. Though this model has been studied in some literatures, there are still less investigations in the context of nonnegative dictionary learning for signal representation. So we focus on nonnegative dictionary learning for signal representation. In this paper, we propose to learn an analysis dictionary from signals using l_1-norm as the sparsity measure. In the formulation, we adopt the Euclidean distance as the error measure. Based on these, we present a new algorithm for the nonnegative dictionary learning and sparse representation for signals. Numerical experiments on recovery of analysis dictionary in the noiseless and noisy situation show the effectiveness of the proposed method.

Academic society activities

[sding-106-005-09:2015] Shuxue Ding, 2015.

Committee member of Technical Committee on Awareness Computing, Systems, Man & Cybernetics Society, IEEE.

[sding-106-005-10:2015] Shuxue Ding, 2015.

Institute of Electrical and Electronics Engineers (IEEE), Membership.

[sding-106-005-11:2015] Shuxue Ding, 2015.

IEEE Signal Processing Society, Membership.

[sding-106-005-12:2015] Shuxue Ding, 2015.

The Institute of Electronics, Information and Communication Engineers (IEICE), Membership.

[sding-106-005-13:2015] Shuxue Ding, 2015.

The Association for Computing Machinery (ACM), Membership.

Advisor for undergraduate research and graduate research

[sding-106-005-14:2015] Kazuya Nemoto. Deep Learning with a Smoothed Rectifier as the Activation Function, Graduation Thesis, 2015.

[sding-106-005-15:2015] Kenji Shibasaki. A Modified Artificial Bee Colony Algorithm with the Gradient Updating, Graduation Thesis, 2015.

[sding-106-005-16:2015] Masato Johoji. Performing Independent Component Analysis by Using the Artificial Bee Colony Algorithm for Optimization, Master Thesis, 2015.

[sding-106-005-17:2015] Kazuki Tsuda. An Optimization Method by the Gravitational Search Algorithm with Mutation Mechanism, Master Thesis, 2015.

[sding-106-005-18:2015] Zhenni Li. Efficient Learning Algorithms for Overcomplete Dictionaries for Sparse Representation of Signal, PhD Thesis, 2015.

Contributions related to syllabus preparation

[sding-106-005-19:2015] Following course planning, I made a syllabus for the Master course: Statistical Signal Processing.

[sding-106-005-20:2015] Following course planning, I made a syllabus for the undergraduate course: Introduction to Topology.

Scholarly paper prepared by undergraduate/graduate student(s) you advised

[sding-106-005-21:2015] Yujie Li, Shuxue Ding, and Zhenni Li. Dictionary learning with the cosparse analysis model based on summation of blocked determinants as the sparseness measure. *Digital Signal Processing (Elsevier)*, 48(10):298–309, Oct. 2015.

[sding-106-005-22:2015] Zhenni Li, Shuxue Ding, and Yujie Li. A Fast Algorithm for Learning Overcomplete Dictionary for Sparse Representation Based on Proximal Operators. *Neural computation*, 27:1951–1982, Sept. 2015.

[sding-106-005-23:2015] Yujie Li, Shuxue Ding, Zhenni Li, and Wuhui Chen. Non-negative Dictionary-Learning Algorithm Based on L1 Norm with the Sparse Analysis Model. *Information Engineering Express (International Institute of Applied Informatics)*, 1(4):1–10, Oct. 2015.

Contribution related to educational planning management

[sding-106-005-24:2015] Graduate School Academic Affairs Committee Member, School of Computer Science and Engineering.

[sding-106-005-25:2015] Evaluation committee member for the projects Competitive Research Funding, projects for FY-2015, University of Aizu

Other significant contribution toward university planning, management, or administration

[sding-106-005-26:2015] Vice-Chair of Graduate Department of Information Technologies and Project Management School of Computer Science and Engineering.