

**Selvan, S. Easter; George, S. Thomas; Balakrishnan, R.**

**Range-based ICA using a nonsmooth quasi-Newton optimizer for electroencephalographic source localization in focal epilepsy.** (English) [Zbl 1414.92186](#)

*Neural Comput.* 27, No. 3, 628-671 (2015).

Summary: Independent component analysis (ICA) aims at separating a multivariate signal into independent nongaussian signals by optimizing a contrast function with no knowledge on the mixing mechanism. Despite the availability of a constellation of contrast functions, a Hartley-entropy-based ICA contrast endowed with the discriminatory property makes it an appealing choice as it guarantees the absence of mixing local optima. Fueled by an outstanding source separation performance of this contrast function in practical instances, a succession of optimization techniques has recently been adopted to solve the ICA problem. Nevertheless, the nondifferentiability of the considered contrast restricts the choice of the optimizer to the class of derivative-free methods. On the contrary, this letter concerns a Riemannian quasi-Newton scheme involving an explicit expression for the gradient to optimize the contrast function that is differentiable almost everywhere. Furthermore, the inexact line search insisting on the weak Wolfe condition and a terminating criterion befitting the partly smooth function optimization have been generalized to manifold settings, leaving the previous results intact. The investigations with diversified images and the electroencephalographic (EEG) data acquired from 45 focal epileptic subjects demonstrate the efficacy of our approach in terms of computational savings and reliable EEG source localization, respectively. Additional experimental results are available in the online supplement.

**MSC:**

[92C55](#) Biomedical imaging and signal processing

[92C20](#) Neural biology

**Keywords:**

[electroencephalographic source localization](#); [independent component analysis](#); [focal epilepsy](#)

**Software:**

[FAME](#); [EEGLAB](#); [BSDS](#)

**Full Text:** [DOI](#)

**References:**

- [1] Absil, P.-A., Mahony, R., & Sepulchre, R. (2008). *Optimization algorithms on matrix manifolds*. Princeton, NJ: Princeton University Press. , · [Zbl 1147.65043](#)
- [2] Albera, L., Kachenoura, A., Karfoul, A., Comon, P., & Senhadji, L. (2010). One decade of biomedical problems using ICA: A full comparative study. In *Proceedings of the World Congress on Medical Physics and Biomedical Engineering* (pp. 2269-2272). Munich: Springer.
- [3] Anemüller, J., Sejnowski, T. J., & Makeig, S. (2003). Complex independent component analysis of frequency-domain electroencephalographic data. *Neural Networks*, 16(9), 1311-1323. ,
- [4] Boscolo, R., Pan, H., & Roychowdhury, V. P. (2004). Independent component analysis based on nonparametric density estimation. *IEEE Transactions on Neural Networks*, 15(1), 55-65. ,
- [5] Byatt, D., Coope, I. D., & Price, C. J. (2004). Effect of limited precision on the BFGS quasi-Newton algorithm. *ANZIAM Journal*, 45, C283-C295. , · [Zbl 1063.65542](#)
- [6] Cardoso, J.-F., & Souloumiac, A. (1993). Blind beamforming for non Gaussian signals. *IEE Proceedings—F Radar and Signal Processing*, 140(6), 362-370. ,
- [7] Congedo, M., Gouy-Pailler, C., & Jutten, C. (2008). On the blind source separation of human electroencephalogram by approximate joint diagonalization of second order statistics. *Clinical Neurophysiology*, 119(12), 2677-2686. ,
- [8] Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, 134(1), 9-21. ,
- [9] Delorme, A., Palmer, J., Onton, J., Oostenveld, R., & Makeig, S. (2012). Independent EEG sources are dipolar. *PloS One*, 7(2), e30135. ,

- [10] De Vos, M., De Lathauwer, L., & Van Huffel, S. (2011). Spatially constrained ICA algorithm with an application in EEG processing. *Signal Processing*, 91(8), 1963-1972. , · [Zbl 1217.94042](#)
- [11] Dirr, G., Helmke, U., & Lageman, C. (2007). Nonsmooth Riemannian optimization with applications to sphere packing and grasping. In F. Allgwer, P. Fleming, P. Kokotovic, A. B. Kurzhanski, H. Kwakernaak, A. Rantzer, & K. Fujimoto (Eds.), *Lagrangian and Hamiltonian Methods for Nonlinear Control* (pp. 29-45). Berlin: Springer. , · [Zbl 1151.53029](#)
- [12] Gómez-Herrero, G., De Clercq, W., Anwar, H., Kara, O., Egiazarian, K., Van Huffel, S., & W. Van Paesschen (2006). Automatic removal of ocular artifacts in the EEG without an EOG reference channel. In *Proceedings of the 7th Nordic Signal Processing Symposium* (pp. 130-133). Piscataway, NJ: IEEE.
- [13] Grin-Yatsenko, V. A., Baas, I., Ponomarev, V. A., & Kropotov, J. D. (2010). Independent component approach to the analysis of EEG recordings at early stages of depressive disorders. *Clinical Neurophysiology*, 121(3), 281-289. ,
- [14] Gulrajani, R. M. (1998). *Bioelectricity and biomagnetism*. New York: Wiley.
- [15] Hild, K. E., Erdogmus, D., & Príncipe, J. (2001). Blind source separation using Renyi's mutual information. *IEEE Signal Processing Letters*, 8(6), 174-176. ,
- [16] Hoeve, M.-J., Zwaag, B. J. v. d., Burik, M. v., Slump, K., & Jones, R. (2003). Detecting epileptic seizure activity in the EEG by independent component analysis. In *Proceedings of the 14th Workshop on Circuits, Systems and Signal Processing* (pp. 373-378). Veldhoven, Netherlands: STW Technology Foundation.
- [17] Huang, W. (2013). *Optimization algorithms on Riemannian manifolds with applications*. Unpublished doctoral dissertation, Florida State University, Tallahassee.
- [18] Huiskamp, G., Maintz, J., Wieneke, G., Viergever, M., & van Huffelen, A. C. (1997). The influence of the use of realistic head geometry in the dipole localization of interictal spike activity in MTLE patients. *Biomedizinische Technik*, 42, 84-87.
- [19] Hunyadi, B., Tousseyn, S., Mijović, B., Dupont, P., Van Huffel, S., Van Paesschen, W., & De Vos, M. (2013). ICA extracts epileptic sources from fMRI in EEG-negative patients: A retrospective validation study. *PloS One*, 8(11), e78796. ,
- [20] Hyvärinen, A. (1999). Fast and robust fixed-point algorithms for independent component analysis. *IEEE Transactions on Neural Networks*, 10(3), 626-634. ,
- [21] Hyvärinen, A., Karhunen, J., & Oja, E. (2001). *Independent component analysis*. New York: Wiley-Interscience. ,
- [22] Hyvärinen, A., Ramkumar, P., Parkkonen, L., & Hari, R. (2010). Independent component analysis of short-time Fourier transforms for spontaneous EEG/MEG analysis. *NeuroImage*, 49(1), 257-271. ,
- [23] Jarchi, D., Boostani, R., Taheri, M., & Sanei, S. (2009). Seizure source localization using a hybrid second order blind identification and extended rival penalized competitive learning algorithm. *Biomedical Signal Processing and Control*, 4(2), 108-117. ,
- [24] Jung, T.-P., Makeig, S., Humphries, C., Lee, T.-W., Mckeown, M. J., Iragui, V., & Sejnowski, T. J. (2000). Removing electroencephalographic artifacts by blind source separation. *Psychophysiology*, 37(2), 163-178. ,
- [25] Knyazev, G. G. (2013). Comparison of spatial and temporal independent component analyses of electroencephalographic data: A simulation study. *Clinical Neurophysiology*, 124(8), 1557-1569. ,
- [26] Latif, M. A., Sanei, S., & Chambers, J. A. (2005). Localization of abnormal EEG sources incorporating constrained BSS. In W. Duch, J. Kacprzyk, E. Oja, & S. Zadrozny (Eds.), *Proceedings of the 15th International Conference on Artificial Neural Networks: Formal Models and Their Applications (Part II)*, pp. 703-708). Berlin: Springer.
- [27] Lee, J. A., Vrins, F., & Verleysen, M. (2006a). A least absolute bound approach to ICA-application to the MLSP 2006 competition. In *Proceedings of the 16th IEEE Signal Processing Society Workshop on Machine Learning for Signal Processing* (pp. 41-46). Piscataway, NJ: IEEE. ,
- [28] Lee, J. A., Vrins, F., & Verleysen, M. (2006b). Non-orthogonal support-width ICA. In *Proceedings of the 14th European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning* (pp. 351-358). Bruges, Belgium: ESANN.
- [29] Lemaréchal, C. (1982). Numerical experiments in nonsmooth optimization. In E. A. Nurminski (Ed.), *Proceedings of the IASA Workshop on Progress in Nondifferentiable Optimization* (pp. 61-84). Laxenburg, Austria: International Institute for Applied Systems Analysis. · [Zbl 0509.65025](#)
- [30] Lewis, A. S., & Overton, M. L. (2013). Nonsmooth optimization via quasi-Newton methods. *Mathematical Programming*, 141(1-2), 135-163. , · [Zbl 1280.90118](#)
- [31] Li, X.-L., & Adali, T. (2010). Independent component analysis by entropy bound minimization. *IEEE Transactions on Signal Processing*, 58(10), 5151-5164. , · [Zbl 1392.94305](#)
- [32] Makeig, S., Bell, A. J., Jung, T.-P., & Sejnowski, T. J. (1996). Independent component analysis of electroencephalographic data. In D. Toretzliy, M. Nozer, & M. Hasselmo (Eds.), *Advances in neural information processing systems*, 8 (pp. 145-151). San Mateo, CA: Morgan Kaufmann.
- [33] Makeig, S., Gramann, K., Jung, T.-P., Sejnowski, T. J., & Poizner, H. (2009). Linking brain, mind and behavior. *International Journal of Psychophysiology*, 73(2), 95-100. ,
- [34] Makeig, S., & Onton, J. (2012). ERP features and EEG dynamics: An ICA perspective. In E. S. Kappenman & S. J. Luck (Eds.), *Oxford handbook of event-related potential components* (pp. 51-86). New York: Oxford University Press.
- [35] Martin, D. R., Fowlkes, C., Tal, D., & Malik, J. (2001, July). A database of human segmented natural images and its application to evaluating segmentation algorithms and measuring ecological statistics. In *Proceedings of the 8th IEEE international conference on computer vision* (Vol. 2, pp. 416-425). Piscataway, NJ: IEEE.
- [36] Miljković, N., Matić, V., Van Huffel, S., & Popović, M. B. (2010). Independent component analysis (ICA) methods for neonatal EEG artifact extraction: Sensitivity to variation of artifact properties. In *Proceedings of the 10th Symposium on*

Neural Network Applications in Electrical Engineering (pp. 19-21). Piscataway, NJ: IEEE. ,

- [37] Milne, E., Scope, A., Pascalis, O., Buckley, D., \& Makeig, S. (2009). Independent component analysis reveals atypical electroencephalographic activity during visual perception in individuals with autism. *Biological Psychiatry*, 65(1), 22-30. ,
- [38] Niedermeyer, E., \& da Silva, F. L. (2005). *Electroencephalography: Basic principles, clinical applications, and related fields*. Philadelphia, PA: Lippincott Williams \& Wilkins.
- [39] Noachtar, S., \& Rémi, J. (2009). The role of EEG in epilepsy: A critical review. *Epilepsy and Behavior*, 15(1), 22-33. ,
- [40] Nocedal, J., \& Wright, S. J. (1999). *Numerical optimization*. New York: Springer. , · [Zbl 0930.65067](#)
- [41] Nunez, P. L., Srinivasan, R., Westdorp, A. F., Wijesinghe, R. S., Tucker, D. M., Silberstein, R. B., \& Cadusch, P. J. (1997). EEG coherency: I: Statistics, reference electrode, volume conduction, Laplacians, cortical imaging, and interpretation at multiple scales. *Electroencephalography and Clinical Neurophysiology*, 103(5), 499-515. ,
- [42] Oliva, A., \& Torralba, A. (2001). Modeling the shape of the scene: A holistic representation of the spatial envelope. *International Journal of Computer Vision*, 42(3), 145-175. , · [Zbl 0990.68601](#)
- [43] Panayiotopoulos, C. P. (2002). *A clinical guide to epileptic syndromes and their treatment*. Oxford, UK: Bladon Medical Publishing.
- [44] Pham, D., \& Vrins, F. (2005). Local minima of information-theoretic criteria in blind source separation. *IEEE Signal Processing Letters*, 12(11), 788-791. ,
- [45] Pham, D.-T., Vrins, F., \& Verleysen, M. (2008). On the risk of using Rényi's entropy for blind source separation. *IEEE Transactions on Signal Processing*, 56(10), 4611-4620. , · [Zbl 1390.94637](#)
- [46] Rényi, A. (1966). *Calcul des probabilités*. Paris, France: Dunod. · [Zbl 0141.14702](#)
- [47] Selvan, S. E. (in press). Nonsmooth ICA contrast minimization using a Riemannian Nelder-Mead method. *IEEE Transactions on Neural Networks and Learning Systems*.
- [48] Selvan, S. E., Amato, U., Qi, C., Gallivan, K. A., Carfora, M. F., Larobina, M., \& Alfano, B. (2012). Descent algorithms on oblique manifold for source-adaptive ICA contrast. *IEEE Transactions on Neural Networks and Learning Systems*, 23(12), 1930-1947. ,
- [49] Selvan, S. E., Borckmans, P. B., Chattopadhyay, A., \& Absil, P.-A. (2013). Spherical mesh adaptive direct search for separating quasi-uncorrelated sources by range-based independent component analysis. *Neural Computation*, 25(9), 2486-2522. , · [Zbl 1418.62248](#)
- [50] Selvan, S. E., Chattopadhyay, A., Amato, U., \& Absil, P.-A. (2012). Range-based non-orthogonal ICA using cross-entropy method. In *Proceedings of the 20th European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning* (pp. 519-524). Bruges, Belgium: ESANN.
- [51] Selvaraj, T. G., Ramasamy, B., Jeyaraj, S. J., \& Selvan, S. E. (2014). EEG database of seizure disorders for experts and application developers. *Clinical EEG and Neuroscience*, 45, 304-309. ,
- [52] Seth, S., Rao, M., Park, I., \& Principe, J. C. (2011). A unified framework for quadratic measures of independence. *IEEE Transactions on Signal Processing*, 59(8), 3624-3635. , · [Zbl 1392.94698](#)
- [53] Stegmann, M. B., Ersbøll, B. K., \& Larsen, R. (2003). FAME—A flexible appearance modelling environment. *IEEE Transactions on Medical Imaging*, 22(10), 1319-1331. ,
- [54] Tang, A. C., Sutherland, M. T., \& McKinney, C. J. (2005). Validation of SOBI components from high-density EEG. *NeuroImage*, 25(2), 539-553. ,
- [55] Vrins, F. (2007). *Contrast properties of entropic criteria for blind source separation: A unifying framework based on information-theoretic inequalities*. Unpublished doctoral dissertation, Université catholique de Louvain Louvain-la-Neuve.
- [56] Vrins, F., Lee, J. A., \& Verleysen, M. (2007). A minimum-range approach to blind extraction of bounded sources. *IEEE Transactions on Neural Networks*, 18(3), 809-822. ,
- [57] Zhukov, L., Weinstein, D., \& Johnson, C. (2000). Independent component analysis for EEG source localization. *IEEE Engineering in Medicine and Biology Magazine*, 19(3), 87-96. ,

This reference list is based on information provided by the publisher or from digital mathematics libraries. Its items are heuristically matched to zbMATH identifiers and may contain data conversion errors. It attempts to reflect the references listed in the original paper as accurately as possible without claiming the completeness or perfect precision of the matching.