Proposition de recherche doctorale

Compressed Sensing Image Acquisition for Dynamic Digital Holography Microscopy

Mots clés :

- **Directeur de thèse** : Jean-Christophe Olivo-Marin
- **Co-encadrant(s)** :
- **Unité de recherche** : Unité d'Analyse d'Images Quantitative
- **Ecole doctorale** : École Doctorale Informatique, Télécommunications, Électronique de Paris
- **Domaine scientifique principal**: Divers

Résumé du projet de recherche (Langue 1)

{{Overview}} This project proposes to study the applications of the mathematical framework of Compressed Sensing (CS) to digital holography microscopy (DHM). It will elaborate dynamic CS DHM imaging protocols and setups based on Fourier-domain measurements with random array detectors and dedicated parameterization of image reconstruction processes. The project will consider the design and implementation of dedicated dynamic compressed sensing acquisition protocols for DHM microscopy imaging. {{Digital Holography Microscopy and CS}} Holographic microscopy is a rapidly growing image-forming method. In particular, its ability to record a diffracted optical field in amplitude and phase on a sensor array is the basis of the successful lensless and diffractive imaging schemes, which are amongst the most promising methods for achieving heavily increased pixel density images with respect to standard image-forming approaches. Optically-acquired holograms have proved to be an efficient and physically realizable sensing modality that can exploit the benefits of compressive sensing, as they are naturally compressed measurements in a reciprocal space. {{Previous work on the project}} This project is the continuation of several years of collaboration between the BioImage Analysis (BIA) group at Institut Pasteur, the Institut Langevin and the Image Processing and Interpretation group at Telecom ParisTech, who specialize respectively in biological image analysis, optical instrumentation and signal and image processing. We are among the very first groups worldwide having proposed and applied the concepts of compressive sensing in biological imaging and demonstrated it in a real biological context. This collaboration has led to two PhD thesis (Marcio Marim in 2010 and Yoann Le Montagner in 2013), which have set the ground of CS-based microscopy imaging, proposing novel and dedicated sensing paradigms, reconstruction algorithms, parameterization strategies, and denoising methods. More recently, we also contributed several original algorithms for CS video acquisitions (Montagner, Angelini et al. 2012), phase retrieval (Montagner, Angelini et al. 2013) and denoising parameterization (Montagner, Angelini et al. 2014). We also published a large set of experiments documenting the choice of CS optimal sampling patterns (Montagner, Angelini et al. 2011b), sampling bounds (Montagner, Marim et al. 2011) and reconstruction algorithms (Montagner, Angelini et al. 2011a). {{Overview of the planned work}} With this project, the goal is to implement CS DHM imaging on real optical setups and video acquisitions, as well as continue algorithmic developments and learning of dedicated dictionaries to handle high level of Poisson-Gaussian noise when working under low-light conditions, high data throughput for video imaging and 3D tomography in DHM. The project will be articulated in three tasks: 1. Modeling and hardware implementation of CS microscopy acquisition with a specific CMOS-random camera, involving realistic simulations of the hardware limitations and temporal versatility, and then programming of the camera for real experimentations with optimized parameterization of the sensing protocol. 2. Design of CS-enhanced holographic microscopy for 3D tomography, low-lights conditions and high-throughput. Three distinct CS optimizations will be investigated: (1) resolving power, pixel density, axial resolution, and signal-to-noise ratio in low-light conditions (involving some learning and modeling of the noise and scattering components); (2) achieving very high-speed imaging, beyond current levels; (3) identifying sparsifying basis tuned to 3D scattering patterns encountered in 3D DH tomography. 3. Previously developed dynamic CS imaging protocols will be implemented, identifying the nature of the temporal DHM information that can be used as updates of a series of images being observed and recorded. This task will be evaluated in the context of in-vivo imaging on small animals.

Résumé du projet de recherche (Langue 2)

Applications of CS imaging are nowadays among the most competitive research topics in image processing (including biomedical imaging), but its use in routine is still limited by several factors. In particular, all CS devices still suffer from limited gains or performance when applied to large-scale data such as real biological microscopy images. Also, although the CS mathematical framework is now mature, the gap towards working CS microscopic devices is still important, and this project proposes to tackle this problem by designing mathematical tools and performing hardware implementations to tune the CS acquisition protocols and reconstruction algorithms to specifically designated and dedicated DHM imaging tasks. The advances of DHM CS imaging will lead to massively increased image acquisition rates with guaranteed resolution and quality. The use of compressed DHM will enable the design of dynamic and 3D tomographic imaging protocols, dedicated to specific biological paradigms and experimental conditions. It should also be of great potential in lifting several severe limitations that still hamper pushing the limits of DHM towards faster image acquisition rates or better image quality and features. {{References}} -* Le Montagner, Y. (2013). Algorithmic solutions toward applications of compressed sensing for optical imaging. PhD, Telecom ParisTech, Ecole Doctoral Edite. -* Marim, M., M. Atlan, E. Angelini and J.-C. Olivo-Marin (2011). "Off-axis compressed holographic microscopy in low-light conditions." Optics Letters 36(1): 79-81. -* Marim, M. d. M. (2010). A Compressed Sensing Framework for Biological Microscopy. PhD, Telecom ParisTech - Ecole Doctorale EDITE. -* Marim, M. d. M., M. Atlan, E. Angelini and J.-C. Olivo-Marin (2010a). Compressed sensing for digital holographic microscopy. IEEE International Symposium on Biomedical Imaging (ISBI). Rotterdam, NL: 684-687. -* Marim, M. d. M., M. Atlan, E. Angelini and J.-C. Olivo-Marin (2010b). "Compressed Sensing with off-axis frequency-shifting holography." Optics Letter 35(6): 871-873. -* Montagner, Y. L., E. Angelini and J.-C. Olivo-Marin (2011a). Comparison of reconstruction algorithms in Compressed Sensing applid to biomedical imaging. IEEE International Symposium on Biomedical Imaging (ISBI), Chicago, USA. -* Montagner, Y. L., E. Angelini and J.-C. Olivo-Marin (2011b). Numerical evaluation of subsampling effects on image reconstruction in compressed sensing microscopy. SPIE 8138, Wavelets and Sparsity XIV. -* Montagner, Y. L., E. Angelini and J.-C. Olivo-Marin (2012). Video reconstruction using compressed sensing measurements and 3D Total Variation regularization for bio-imaging applications. IEEE Conference on Image Processing (ICIP), Orlando, FL, USA. -* Montagner, Y. L., E. Angelini and J.-C. Olivo-Marin (2013). Phase retrieval with sparsity priors and application to microscopy video reconstruction. IEEE International Symposium on Biomedical Imaging (ISBI), San Francisco, CA, USA. -* Montagner, Y. L., E. D. Angelini and J.-C. Olivo-Marin (2014). "An unbiased risk estimator for image denoising in the presence of mixed Poisson-Gaussian noise." IEEE Transactions on Image Processing 23(3): 1255-1268. -* Montagner, Y. L., M. Marim, E. Angelini and J.-C. Olivo-Marin (2011). Numerical evaluation of sampling bounds for near-optimal reconstruction in Compressed Sensing. International Conference on Image Processing (ICIP), Brussels, Belgium,.

Informations complémentaires (Langue 1)

The results of this work will be presented at major international conferences of the domain, typically IEEE ISBI and ICIP, and OSA Holography. Elsa Angelini is currently based at Columbia University, New York, USA and holds a joint appointment between Columbia University and Telecom ParisTech. Regular visits of the PhD student at Columbia University will therefore be planed.