The SpaceFusion project

Image fusion from multiple sources (taken with different sensors, resolution or even spectral bands) consists of estimating a single model, of arbitrary spatial and spectral resolutions. The goal is to recover a geometric and radiometric object that embeds the information present in the initial data. The originality of the approach is in the integration of the data acquisition process with a model of the object to be reconstructed (2D image or 3D surface). To this end, we proposed to use Bayesian inference, which aims at the a posteriori probability density function of the model parameters given all the observed images, containing both an optimal model and the related uncertainty estimate.

Main contributions:

• The use of a single parametric model that contains useful information from various sources, in a natural and user-friendly way.

• Modeling of the image formation process (geometry, point spread function, sampling), depending on the application area and data type, based on the physics of image acquisition, through parametric or non-parametric models that are simple but flexible.

• Bayesian inference and graphical model theory used for forward modeling, and inversion by way of marginalization and functional optimization, as well as the related approximations necessary to develop a fast and deterministic algorithm. It enables us to estimate model uncertainties as well.

• Data fusion used as a tool to deal with data redundancy while taking advantage of their complementarity, implicitly minimizing the information loss. Thanks to uncertainty evaluation, the fusion can be performed recursively when new data become available to update the current model, thus allowing for large amounts of data to be processed.

Recent results and achievements:

• The theoretical framework allowing for signal and image data fusion was established rigorously and a new methodology was developed (see figure on the right for an illustration of the image resampling method devised to perform astronomical data fusion). A journal paper was published, showing promising results on synthetic data (see illustration next page). These results show that it is possible to obtain a well-sampled, super-resolved image from undersampled data corrupted by noise.

• Interactions with astronomers confirmed the relevance of most of the initial objectives and the effectiveness of the proposed approaches, and helped to point out a few problems related to the validation of the developed technique. Indeed, the astronomical community needs to be convinced that they would benefit from learning and using the new method, despite the increased complexity with respect to state of the art methods (simple but unsatisfactory from my statistical point of view). The main issue is in the understanding and the use of the computed uncertainties, provided as an inverse covariance matrix (see illustration below for the proposed storage scheme). Covariances carry important information that ought to be taken into account properly, which sometimes requires to redesign classical and widely used measurement methods. Therefore a communication effort is required, as well as well-designed tests on simple but popular problems in the field (astrometry, photometry, detection). The collaboration with the Observatory of Strasbourg was set up to help promote the technique within the French and European Virtual Observatories. This is still work in progress.
Concerning 3D surface rendering, we noticed that one can take advantage of the fact that optical systems have a limited resolution (due to the transfer function), therefore geometric techniques based on triangles (elements of surfaces modeled by triangular meshes) can be advantageously replaced by simpler and faster methods relying on sums of Gaussian kernels, even for visibility computations. Inspired by the splatting theory popular in computer graphics, we started developing a theory to avoid expensive geometric computations while preserving the rendering quality. It should allow us in the future to visualize elevation models and the related errors as well, since it would be able to render fuzzy surfaces.

After several seminars in France and in the USA it became clear that the multidisciplinary aspects of the projects are of great interest, particularly the possibility of propagating errors when computing multispectral terrain reflectance in planetary sciences, or the ability to use byproducts such as the deformation (or disparity) map in Earth science, to derive the ground motion related to earthquakes. However, the main focus shifted from pure fusion to radiometric change detection and management, not only for robustness issues related to these changes, but also because such changes are of interest. Then, except for astronomy, the goal is not anymore to build a single radiometric map but rather to register all observations in a compound object that is easier to use than the original data. It comes down to producing elevation models and orthorectified imagery, with the specificity related to uncertainties (e.g. uncertain elevation models and fuzzy resampled images) - one of the main contributions of the project.

A new method was developed to estimate the dense disparity or deformation map between two images. It is based on nonrigid deformation using B-Spline resampling, and a model of radiometric changes. This can be used as it is (for ground deformation monitoring, related to earthquakes, erosion or volcanic activity) or to derive elevation models and accurate image acquisition parameters. Two successive versions were detailed in conference papers, with results from real images (SPOT 5, see illustration below for some recent results) and a new version is currently under development.

There were three major challenges: a) the robustness to radiometric changes, tackled through a semi-parametric adaptive change map; b) the ability to compute relevant uncertainty estimates; c) escaping the multiple optima due to nonlinear optimization. Issues b) and c) were recently addressed through approximate inference methods based on graphical model theory. The new technique is able to provide a high resolution and sub-pixel accurate deformation estimate at the same time, which existing methods never achieve simultaneously - however, the spatial error map is the most significant and original contribution. Research in progress includes accurate camera calibration from disparities and existing elevation models, and a conversion scheme from disparity to elevation model that allows to propagate errors from measured disparities and calibration parameters as well.
Left: color-coded vector disparity map estimated from a pair of SPOT 5 images taken before and after the Bam, Iran earthquake (Dec 26, 2003); stereo parallax 7.4°. Center: and E-W projection of the deformation map to show the topography. Right: standard deviation map (Monte Carlo inversion of the inverse covariance), range: [black=0.03, white=0.12] pixels.

Left: color-coded vector disparity map and proposed actual fault trace in red. Center: N-S projection of the deformation map (eliminating most topographic artifacts). Right: standard deviation map (Monte Carlo inversion of the inverse covariance) [black=7, white=18] cm

Publications:

International Journals

International Conferences (peer-reviewed papers)
3. A. Jalobeanu, D.D. Fitzenz: “Robust disparity maps with uncertainties for 3D surface reconstruction or ground motion inference” - ISPRS Proc. of Photogrammetric Image Analysis (PLA’07), Munich, Germany, Sep 2007
5. A. Jalobeanu, E. Slezak, J.A. Gutiérrez: “Multisource data fusion and super-resolution from astronomical images” - Astronomical Data Analysis IV (ADA IV), Marseille, France, Sep 2006
7. A. Jalobeanu: “Multisource data fusion and super-resolution from astronomical images” - Statistical Challenges in Modern Astronomy IV (SCMATIV), Penn State, PA, USA, Jun 2006