Abstract

Multispectral and Hyperspectral Pansharpening: A Critical Examination and New Developments

Remote sensing consists in measuring some characteristics of an object from a distance. A key example of remote sensing is the Earth observation from sensors mounted on satellites that is a crucial aspect of space programs. The first satellite used for Earth observation was Explorer VII. It has been followed by thousands of satellites, many of which are still working. Due to the availability of a large number of different sensors and the subsequent huge amount of data collected, the idea of obtaining improved products by means of fusion algorithms is becoming more intriguing. Data fusion is often exploited for indicating the process of integrating multiple data and knowledge related to the same real-world scene into a consistent, accurate, and useful representation. This term is very generic and it includes different levels of fusion. This dissertation is focused on the low level data fusion, which consists in combining several sources of raw data. In this field, one of the most relevant scientific application is surely the *Pansharpening*.

Pansharpening refers to the fusion of a panchromatic image (a single band that covers the visible and near infrared spectrum) and a multispectral/hyperspectral image (tens/hundreds bands) acquired on the same area. It can be seen as data fusion because one would aim at combining in a single product the spatial details resolved by the panchromatic image, but not present in the multispectral/hyperspectral image, and the multiple spectral bands of the other image characterized by a greater spectral content. The fusion of these data compensates the unavailability of images with high resolutions in both domains, which are precluded by physical limits of remote sensor realizations and by the necessity of alleviating problems, such as, the data storage on-board and the transmission to ground stations. Very popular software, such as Google Earth, exploit these algorithms to provide enhanced products to final users. In the latest years, the possibility of applying them as preprocessing for some algorithms has been also exploited.

This thesis firstly shows an overview of the broad existing literature, together with the classification of the approaches into two main families: *Component substitution* and *multiresolution analysis*.

A classical pansharpening algorithm can be divided into two phases: Detail extraction and injection. By focusing on the former, many powerful approaches exploit the functional relation between the panchromatic and multispectral images. To this purpose, the modulation transfer function of the higher spectral resolution sensor is typically used. Approximations based on Gaussian filters whose analytic expression is fully specified by the sensor gain at the Nyquist frequency are usually performed. However this characterization is often inadequate in practice, or, in some cases, the gains at the Nyquist frequency could be unavailable. In order to overcome these limitations, a *deconvolution algorithm* for estimating the relation between panchromatic and multispectral images directly from the available data is proposed. Furthermore, a critical

analysis and comparison among the state-of-art extraction detail approaches is provided to justify the advantages.

With reference to the other main step of pansharpening algorithms, i.e., the injection of the previously extracted details, the comparison of the two most popular models (i.e., the ones based on *error* and *contrast*) is performed. An analysis in the light of physical considerations regarding the point spread function is shown together with the derivation of the constraint on the modulation transfer functions in terms of image local contrast. Moreover, the superiority of the contrast injection model from a quantitatively and qualitatively points of view is pointed out under different conditions (i.e., by varying both the datasets and the extraction detail phase).

The pansharpening problem is usually related to the fusion of multispectral and panchromatic images. Few attempts of fusing hyperspectral images are present in the literature. For this reason, we firstly investigate the use of *classical pansharpening approaches* in the *hyperspectral* case underling the superiority of algorithms into the multiresolution analysis family thanks to the greater spectral consistency. Then, the specific issues in fusing of hyperspectral data, such as, the increasing of both the computational burden and the spectral distortion, are considered. In order to overcome the computational limits, the application of techniques, which are able to reduce the dimensionality of hyperspectral data, are surely advisable. In the literature, one of the most used to reach this goal is the Principal Component Analysis (PCA). Here we propose the use of the *non-linear PCA*, which exploits auto-associative neural networks, and compare its performances with the classical linear PCA. Moreover, at the aim of reducing also the spectral distortion, *hybrid approaches* can be exploited. In fact, after the reduction step, we only inject the spatial details of the panchromatic image into one or more selected components instead of substituting it. The findings demonstrate how the non-linear PCA is more suitable than the linear one in reducing the spectral dimension of hyperspectral data and that the hybrid approaches reduce both the spectral distortion and the computational effort.

Finally, an experimental activity requires a proper implementation of the validation procedures, quality indexes, algorithms for the comparison and preprocessing procedures. For these reasons, after a collaboration among the GIPSA-Lab (Grenoble Institute of Technology), the universities of Florence, Siena, Salerno and the MINES ParisTech, a *MATLAB Toolbox* has been developed, which allows, starting from multispectral and panchromatic images, the comparison of several algorithms belonging to the state-of-art; it exploits the two main validation procedures (i.e., at reduced and full scale) and the commonly used quality indexes. This work represents a step towards the standardization of some processes and, after its spread on the net, it will help all the researches who want to propose a new pansharpening algorithm, making easier the improvements in this scientific area. Another goal of this work is the critical comparison of the existing pansharpening methods, which has not yet been sufficiently investigated. Indeed, in this thesis, a wide analysis of several state-of-art approaches by the means of the two main validation protocols for the performance assessment is performed and the differences in performance of the several algorithms are pointed out on the various datasets.