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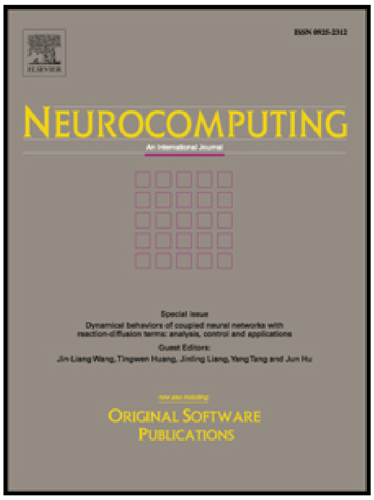

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Mattia Natali, Giulio Tagliafico, Giuseppe Patanè

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Local Up-Sampling and Morphological Analysis of Low-Resolution Magnetic Resonance Images

Mattia Natali[a], Giulio Tagliafico[a], Giuseppe Patanè[a]

[a]CNR-IMATI, Genova - Italy
{natali,tagliafico,patane}@ge.imati.cnr.it

Abstract

Limitations in the resolution of acquired images, which are due to sensor manufacturing and acquisition conditions, are reduced with the help of algorithms that enhance the spatial resolution by assigning pixel values that are interpolated or approximated from known pixels. We propose a variant of the moving least-squares approximation for image up-sampling, with a specific focus on biomedical MR images. For each evaluation point, we locally compute the best approximation by minimizing a weighted least-squares error between the input data and their approximation with an implicit function. The proposed approach provides a continuous approximation, an accuracy and extrapolation capabilities higher than previous work, and a lower computational cost. As main application, we consider the up-sampling of low field MR images, where the volumetric and meshless properties of the approximation allow us to easily process images with anisotropic voxel size by rescaling the image and inter-slices resolution. Finally, we include the resolution rescaling into a pipeline that performs a morphological characterization of 3D anatomical districts, which has been developed with a focus on rheumatoid arthritis evolution and provides a more accurate segmentation as an input to quantitative analysis.

Keywords: Biomedical informatics and mathematics, computer-aided diagnosis, image segmentation and feature extraction, image up-sampling and enhancement, quantitative analysis, moving least-squares approximation.

1. Introduction

Imaging hardware, acquisition methodologies and time, overlap of different tissues, physiological and pathological phenomena generally limit the image resolution. To partially overcome these drawbacks, a relatively small number of 2D slices is acquired at the cost of a larger slice thickness and space between slices; as a result, the resolution in the slice direction is lower than the resolution in the acquisition plane. Furthermore, noise, non-uniform intensity, and partial volume averaging generally affect anisotropic MR images, make their analysis error-prone, and generate blurring effects or "distorted" reconstructions of the underlying geometries. For instance, a single tissue might have a non-uniform intensity over the acquired images, due to a different homogeneity of the tissue itself, or some pixels might show an average intensity in those regions where different tissues overlap. All these elements are further complicated by the tissue variability among individuals and their morphological complexity.

In this context, *image up-sampling* tackles the problem of increasing the resolution of an image, or more generally a set of images composing a volumetric data set, by preserving its main features (e.g., sharp edges, textures) and removing artifacts (e.g., blurring, pixel blocking). In medical applications, image up-sampling is crucial for segmentation and analysis, where algorithms are typically limited by the data resolution, anisotropy, and blurring. In all these cases, the higher the image resolution is, the more accurate the analysis is (e.g., segmentation, quantitative and morphological analysis). Main features of image up-sampling are processing speed for prompt user interaction, sharpness on the whole image, preservation of image textures, low influence of parameters in the results, and low memory consumption. Visual properties to be preserved are the image contrast, the absence of blocky regions, and the contour sharpness.

The *quantitative analysis* of low resolution images is generally affected by their transformation to a different space or representation (e.g., through image regis-