Comparison Between Parzen Window Interpolation and Generalised Partial Volume Estimation for Nonrigid Image Registration Using Mutual Information

Dirk Loeckx, Frederik Maes, Dirk Vandermeulen, and Paul Suetens

Medical Image Computing (ESAT/PSI), Faculty of Engineering
University Hospital Gasthuisberg, Herestraat 49, B-3000 Leuven, Belgium
Dirk.Loeckx@uz.kuleuven.ac.be

Abstract. Because of its robustness and accuracy for a variety of applications, either monomodal or multimodal, mutual information (MI) is a very popular similarity measure for (medical) image registration. Calculation of MI is based on the joint histogram of the two images to be registered, expressing the statistical relationship between image intensities at corresponding positions. However, the calculation of the joint histogram is not straightforward. The discrete nature of digital images, sampled as well in the intensity as in the spatial domain, impedes the exact calculation of the joint histogram. Moreover, during registration often an intensity will be sought at a non grid position of the floating image.

This article compares the robustness and accuracy of two common histogram estimators in the context of nonrigid multiresolution medical image registration: a Parzen window intensity interpolator (IIP) and generalised partial volume histogram estimation (GPV). Starting from the BrainWeb data and realistic deformation fields obtained from patient images, the experiments show that GPV is more robust, while IIP is more accurate. Using a combined approach, an average registration error of 0.12 mm for intramodal and 0.30 mm for intermodal registration is achieved.

1 Introduction

The goal of image registration is to find a transformation that maps positions of a reference image I_R onto the corresponding positions of a floating image I_F and is optimal in some sense. Different ways exist to judge the similarity between the reference and (deformed) floating image. They can be broadly classified into two categories: feature based and intensity based methods. In 1995, Collignon *et al.* [1] and Viola *et al.* [2] independently introduced mutual information (MI) as a similarity measure for intensity based medical image registration. Because of its robustness and accuracy for a variety of applications, either monomodal or multimodal, its popularity has been growing ever since [3, 4].

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Calculation of MI is based on the joint histogram of the two images to be registered, expressing the statistical relationship between image intensities at corresponding positions. However, the sought-after transformations will usually map pixels, located at integer positions in the reference image, to non integer locations in the floating image. This, together with the discrete nature of digital images, impedes the exact calculation of the joint histogram. In most cases, the intensities at the non integer locations are found by some kind of image interpolation in the floating image. Several reference articles have been published comparing different interpolators, yet no consensus exists on the best method [5, 6]. The joint histogram is usually constructed by grouping corresponding intensities in discrete, distinct bins [7, 5]. Alternatively, Thevenaz *et al.* [8] used a B-spline Parzen window approach to smooth the histogram bins.

As early as in 1997, Maes *et al.* [9] introduced partial volume distribution interpolation, an alternative method for the construction of the joint histogram. No interpolation is used to estimate the unknown intensities. Instead, each reference intensity is paired with the intensities of the voxels neighbouring the non integer location in the floating image. For each joint intensity pair, the histogram is updated with a partial hit, using a trilinear kernel to weight the contribution. Recently, Chen *et al.* [10] extended this approach to generalised partial volume estimation, using higher-order B-spline kernels for the weighting to reduce the artifacts.

Within this article, the B-spline Parzen window approach using intensity interpolation and the generalised partial volume estimation approach are compared using a single dataset, deformation model and optimisation algorithm. Both algorithms are implemented using an analytical expression for the derivatives. Nonrigid registration involves a huge number of degrees of freedom. To reach the optimum in an acceptable time-span, calculation of the derivative of the similarity criterion with respect to the deformation parameters is required. Although those derivatives can also be calculated numerically, as e.g. in [11], analytically calculated derivatives are less sensitive to noise and therefore might lead to a better registration.

This paper is organised as follows. In the methodology section, more details about both histogram estimators, the B-spline deformation mesh and the optimisation and validation algorithm are given. Next, the experimental setup and results are presented. We finish with a short discussion and some indications for future work.

2 Implementation

2.1 Histogram Estimation

For the histogram estimation, B-spline intensity interpolation (IIP) [8] and (B-spline) generalised partial volume estimation (GPV) [10] are compared. In both cases, a quadratic B-spline kernel is used, either for the image interpolation and Parzen window (IIP) or for the histogram distribution weights (GPV). The