Pattern Recognition 43 (2010) 4011–4027

Contents lists available at ScienceDirect

Pattern Recognition

journal homepage: www.elsevier.com/locate/pr

Multimodal genetic algorithms-based algorithm for automatic point correspondence

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ARTICLE INFO

Article history:
Received 2 October 2008
Received in revised form
28 February 2010
Accepted 10 June 2010

Keywords:
Automatic correspondence
Point extraction
Multimodal GAs optimization
Image registration
Elastic deformation
Medical images

ABSTRACT

In this paper, the problem of automatic determination of point correspondence between two images is formulated as a multimodal function optimization and the usefulness of genetic algorithms (GAs) as a multimodal optimizer is explored. Initially, a number of variations of GAs, capable of simultaneously discovering multiple extremes of an objective function are evaluated on a mathematical benchmark objective function with multiple unequal maxima. The variation of the GAs that performs best on the benchmark function, in terms of the number of maxima discovered, is selected for the determination of automatic point correspondence between two images. The selected variation of the GAs involves an iterative procedure for the formation of a genetic population of individuals (or chromosomes). Each individual encodes the position of a point of interest on one of the available images as well as parameters of a local transformation that generates the position of the corresponding point on the other image. The proposed algorithm aims to discover individuals that corresponds to local maxima of an objective function that measures the similarity between patches of the two images. When the GAs-based multimodal optimization algorithm terminates, pairs of corresponding points between the two images are obtained that can be used for the generation of a dense deformation field by means of the thin plate splines model.

The proposed algorithm is applied to 2D medical images (dental and retinal images) under known transformations (similarity and elastic transformation) and is also assessed on medical images with unknown transformations (computer tomography transverse slices). The proposed algorithm is compared against the iterative closest point (ICP) algorithm, and a well-known non-rigid registration algorithm, based on free-form deformations (FFD) using various quantitative criteria. The obtained results indicate that in case of known similarity transformations, the proposed multimodal GAs-based algorithm and the ICP algorithm present equivalent performance, whereas the FFD algorithm is clearly outperformed. In the case of known sinousoidal deformations, the proposed multimodal GAs-based and the FFD algorithm achieve equivalent performance and clearly outperform the ICP algorithm. Finally, in the case of unknown elastic deformations, the proposed GAs-based algorithm appears to perform marginally better than the FFD algorithm, whereas it clearly outperforms the ICP algorithm.

1. Introduction

Detection of correspondence between image feature points is a necessary task in a number of image processing applications, such as geometric alignment of two or more data sets [1], recovery of 3D shape from 2D images [2], object segmentation [3], determination of camera location [4], motion analysis [5], structure from motion [6], determination of subject's point of gaze [7]. Particularly, the ability to calculate accurate and robust correspondence is more vital in the medical and biological domains in order to measure organ growth [8], align histological sections [9], register medical data [10,11], perform virtual surgical planning [12], segment anatomic structures [13], etc.

There is no general solution to the problem of correspondence. Specifically, the detection of pairs of corresponding points involves the extraction of salient anatomical or geometrical interest points. The interest points are distinctive points of the morphology of the imaged structures, identified either manually by the user or automatically. The interest point detection methods can be divided into three categories: contour-based, intensity based and parametric model-based methods. Contour-based methods include a segmentation step that aims at extracting

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doi:10.1016/j.patcog.2010.06.009

contour lines. Subsequently, the interest points are the locus of maximal curvature [14,15], inflexion points [16] or wavelet transform modulus maxima [17] along the contour lines. Alternatively, the interest points can be obtained from the intersections of the polygonal approximation of the contour lines [18]. In intensity based methods, a suitable measure, which indicates the presence of an interest point, is calculated directly from the gray values of the image [19,20]. Parametric model-based methods fit a parametric intensity model to the image [21,22]. They often provide sub pixel accuracy, but are limited to specific types of interest points, for example to L-shaped corners.

After the detection of the interest points, the correspondence between them can be established. One of the most popular methods for finding homologous points in two images is template matching [23], where correspondences are obtained by comparing image patches centered at the interest points of the two images. The popularity of using template matching for applications of image processing lies in its simplicity of implementation in conjunction with the many fast algorithms that can be used to speed up the matching process for various applications [24,25]. The iterative closest point (ICP) algorithm [26] is also broadly used for allocating corresponding points due to its robustness, simplicity and fast execution time. This is an iterative algorithm that utilizes the nearest neighbor relationship to assign correspondences between the candidate points of the two images at each step. In [27], robust correspondences are established by determining the sensitivity of each tentative correspondence to movements of the point being matched. A point matching algorithm under large image deformations and illumination changes is presented in [28]. In [29], a point correspondence algorithm towards registration of multimodal retinal images is presented based on the theory of self-organizing maps and requires the extraction of interest points (bifurcations) only in one image.

Point correspondence has been also formulated as an optimization problem. In [30], the simplex optimization method has been implemented to find a global solution of a concave objective function towards automatic correspondence of stereo images. Extremal dynamics, as a new optimization technique, were used to define robust point correspondence towards image registration [31]. A particle swarm optimization method has been also introduced for the point pattern-matching problem to define correct correspondence of extracted points [32].

Genetic algorithms (GAs) have been applied towards automatic point correspondence and template matching. A GAs-based approach has been introduced to point correspondence of a pair of stereo images [33]. This approach treats the problem as an unimodal combinatorial optimization one and therefore employs an appropriately adapted version of the standard GAs. Zhang et al., in [34], introduced a GAs-based method for the incomplete point pattern-matching problem under general affine transformation using partial Hausdorff distance. The algorithm operates on static point sets, without dynamically updating their position, whereas the employed GAs optimization method is based on the classical implementation of the GAs without the use of genetic operators for multimodal search. In [35], a method of GAs-based optimization has been applied to the problem of image stereo matching in order to determine the adaptive disparity map between the different projections. However, this approach is sequentially applied to image blocks, encoding a two-dimensional (2D) disparity map into the population of individuals without simultaneously maintaining a number of solutions for each image.

In the aforementioned approaches, GAs-based optimization algorithms were used in their standard implementation, also known as *simple GAs*, as described in [36]. According to the simple GAs, solutions of the optimization problem are randomly produced and encoded into the genetic material (chromosomes) of individuals. GAs maintain and evolve a population of individuals. An individual is assigned a fitness value equal to an objective function evaluation for the independent parameters encoded in it. A selection operator selects individuals according to their fitness to produce offspring according to "crossover" operator that allows the creation of new individuals by recombining the parents. When a new generation of offspring is created, it replaces the current generation of individuals and the algorithm repeats itself until the satisfaction of a termination criterion.

The simple GAs are very efficient in discovering the global optimum in a multidimensional fitness landscape that presents a number of local optimums, without being trapped into local optimums. However, in doing so, the simple GAs ignore all the other local optimum points of the fitness landscape. In certain optimization problems, the discovery of a number of objective function optimum points, rather than a single global one, is of great importance [36,37].

In this specific study, the problem of point correspondence between two 2D images is formulated as optimization of a function that exhibits multiple optima (multimodal function). Thus, the usefulness of a multimodal GAs-based optimization algorithm to discover pairs of corresponding points is investigated by comparing combinations of different offspring placement operators and parent selection operators. Specifically, two offspring placement operators, named the deterministic crowding algorithm (DC) [38,39] and the restricted tournament selection algorithm (RTS) [40], were tested in conjunction with two selection operators, named the roulette wheel selection (RW) [41] and restricted mating (RM) [43]. The selection and fine tuning of the best performing multimodal GAs variation was obtained using a well-known 2D mathematical function with multiple unequal extremes.

Subsequently, the multimodal GAs-based algorithm that was defined and fine tuned above is utilized to optimize an objective function towards automatic point correspondence of a pair of 2D images. Each individual of the genetic population contains the coordinates of a point of interest from one image and the parameters of local transformation that indicates the position of the corresponding point on the second image. The objective function measures the similarity between a patch from the first image, centered at the point of interest contained in an individual, and its transformed counter-part from the second image using the transformation parameters of the current individual. As the GAs-based optimization algorithm evolves, it detects multiple candidate point positions on the first image, whereas the aforementioned local transformation parameters define the homologous point positions on the second one. It is the requirement of simultaneous detection of a large number of optimally placed corresponding points between a given pair of images that necessitates the use of a multimodal optimization technique, such as GAs. After completion of the GAs evolution, a set of corresponding point pairs is defined by an equal number of individuals of the population, and it is used to generate a dense deformation field, using the thin plate splines model. The proposed multimodal GAs-based algorithm was applied to 2D real medical images (dental and retinal images) under known transformation and CT slices under unknown transformation. Finally, the performance of the proposed GAs-based algorithm was also compared against the iterative closest point (ICP) algorithm [49–51], as well as a non-rigid intensity based registration method using free-form deformations (FFD) [52,53].

The paper is organized as follows: Section 2 presents the formulation of the problem of identifying pairs of corresponding points between two images as a multimodal optimization problem and the analytical description of the proposed