High level vision with the Deformable Pyramid

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RÉSUMÉ

Une pyramide de graphes, constituant un modèle multirésoltuion déformable est utilisée pour la reconnaissance de formes. Cette pyramide permet de décrire des formes complexes par des maillages de leur surface, elle est construite à partir d'un volume de référence. Le modèle est ensuite déformé pour s'adapter aux données tout en conservant ses propriétés topologiques et géometriques. Cette nouvelle méthode permet l'extraction rapide, robuste et précise du modèle dans le cadre de l'imagerie cardiaque volumique par résoance magnétique. Les potentialités de la pyramide déformable sont illustrées par l'extraction d'un modèle du thorax et du coeur en mouvement.

ABSTRACT

A new multiresolution deformable model, based on a pyramid of graphs, is used for pattern recognition. The pyramid allows to describe complex shapes using a set of simple primitives composed of nodes, links and triangles. The pyramid is built out of a reference volume containing previous knowledge of the objects. A fitting algorithm is used to deform the model in a constrained manner. The topological and the main geometrical properties of the model are preserved and at the same time, the model adapts itself to the input data. This new method provides fast, robust and accurate model extraction in 3D magnetic resonance images. The efficiency of the deformable pyramid is illustrated on individual torso and dynamic heart model extraction.

1 Introduction

Computer vision of dynamic 3D objects requires flexible models to track complex deformations. A second constraint is the insensibility to noise corrupted information. The model has to provide complete information about the geometry and the kinetic of the objects. Most of the proposed deformable models introduce flexibility as the principal property [4][1][6]. These methods are usually based on thin-plate under tension. They lack robusteness to noise as there is no information about the real shape of the object. The second class of deformable models uses previous knowledge of the studied objects, resulting in higher robustness to noise. The knowledge integration into the model is achieved through a template [3], some computed statistics about a mean representative shape [2], the low-order mode of vibration of the shape using Eigen decomposition [9] or Fourier descriptors [11]. This paper presents a new method that combines several of these aspects. A template containing binary description of the topology and geometry of the objects is used to introduce the previous knowledge. A multiresolution triangulation on the interfaces is performed [5], providing a 3D static model. A dynamic deformation process based on a smooth transformation is established to fit the model to the data. Some high-level constraints are introduced in the process yielding a good accuracy of the solution with preservation of the main objects properties. At the end of this paper extraction of the epicardium of the heart using magnetic resonance imaging is shown.

2 Building the reference pyramid

A classical model for objects representation is the definition of their external surface. A reference volume contains a binary representation of the organs [5]. In this volume, each voxel is labelled with a value corresponding to a specific organ. This binary pyramidal representation is established once using a standard MR volume with a high contrast between organs and overall low noise level. Three levels of resolution are used in the pyramid for the experiments. They provide vertical structuration of the information [8] that is useful for the fitting algorithm. The two main features of the reference pyramid are the topological and geometrical properties imposed to the extracted solution. The typical shape of an organ is modeled using a tesselation of the reference surface. The fitting algorithm uses only the position of the nodes of the triangles, without any assumption about the mass, stiffness or damping of the underlying material. The aim of the fitting algorithm is to deform the model toward the salient features contained in the input data. The fitting algorithm consists of two parts : the selection of features in the study volumes and the definition of a deformation algorithm for the pyramid.

3 The fitting algorithm

Once the reference pyramid is built, a fitting algorithm is used to extract individualized models in input volumes. This algorithm has to fulfil two different goals : one goal is to limit the amount of deformation of the model so that it still represents the reference model, the other goal is to obtain a high quality of fit to the input data. Data are thresholded [7], providing an unstructured set of primitives like partial edges of the objects. These primitives are organised by attracting the reference points of the model towards them and imposing the chosen parameterization of the model. The first step for adapting the model to the data is to define a displacement vector for each point of the model so that the translated point will fall on a salient point of the data. The data point set is noisy and uncomplete : by applying the raw set of transformation an inappropriate solution is achieved. The second step is to control the displacement field by using a basis of smoothed deformation functions. The projection of the raw deformation field on the defined basis allows to control the amount and the smoothness of the deformation.

Deformation algorithm : The pyramid is deformed using global and local transformations. Global transformations like translation, rotations and scaling are used to roughly recover the objects of interests in various acquisition conditions. The local deformation is based on the Bernstein polynomials [10]. The polynomial deformation provides very satisfactory results and is one of the most simple and fast method to use. The reference object is included in its bounding box, defining a parametrization for each point that will lie in $(0, 0, 0), (1, 1, 1)$. A grid of $l.m.n$ control points is formed by sampling the bounding box. These points are the control points set of the deformation. The Bernstein polynomials have the property that their values lie between 0 and 1. Assembled through a tensorial product, they define a 3-space to 3-space transformation.

Multiresolution algorithm : The deformation paradigms are integrated in an energy function which is minimized by using a multiresolution deterministic approach. The energy E is given by $E = \gamma E_d + E_f$, where E_d is the deformation energy of the pyramid and E_f is the fit energy to the data. Both energy are measured as an euclidian distance : control points translation from original positions for E_d and nodes distance to the data points for E_f. The goal of the fitting algorithm is to minimize the energy E. This function is not unimodal and it is complex over the deformation parameter space. Using Gibbs sampler, stochastic diffusion algorithm, simulated annealing, genetic algorithms or others methods based on stochastic exploration of the space of solutions, it is possible to find the minimum of the global energy. However, these algorithms obtain the minima at the cost of excessive computations for real-time applications. The multiresolution approach provides efficient minimization even if there is no certainty about the location of the global minimum. The fitting algorithm is initiated at the higher level of the pyramid. The parameter γ is used to provide control on the deformation of the pyramid. A high value of γ implies a high cost for large local deformations and thus implies a more rigid model.

4 Application to MR volumes of the heart

The accuracy of the solution measured as the mean distance of the deformed pyramid to the real object surface is less than 0.3 voxel. Mean time execution is about two minutes for a 128x128x128 volume on a IBM RS6000 workstation. The deformable model has extracted the epicardium of the heart while removing the pulmonary vessels that were not included in the reference model.

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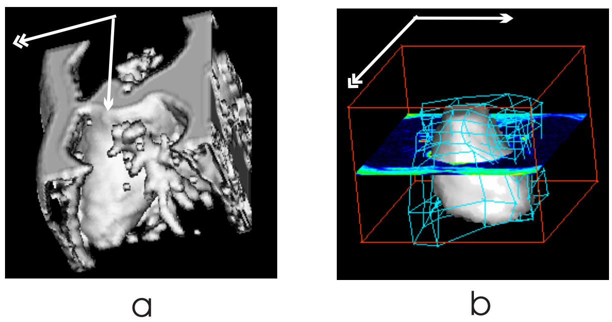

FIG. 1 — (a) Side view of rendered raw MR data, (b) Antero/posterior view of the deformed model with the control box.

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