Disparity Analysis for Image Fusion

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Abstract

The contribution presents the idea of using disparity analysis as a tool in image fusion. Fusion of images of the same scene, provided with different parameters, different imaging modalities or from different aspects, may enable obtaining information that is unavailable from the individual images. An important step in image fusion is often registration of images, i.e. finding a geometrical transform, which matches one image (or more images) to the reference image of the set. The purpose of this contribution, besides summarising the methodology of disparity analysis, is to point to manifold applications of disparity maps derived in this way. The maps may serve e.g. as a basis for stereo analysis – deriving the third dimension from a couple of images, as in [1]. Another important use is in motion or growth analysis applied in image/video sequences. The contribution describes the way how disparity maps may form a ground for image registration, i.e. how to obtain the parameters of even complex nonlinear flexible transforms, possibly piecevice defined, based on detailed disparity maps.

Introduction

Image fusion is defined as deriving a new knowledge from a set of two- or more images (two-dimensional or three-dimensional image data) describing the same or similar scene that differ either in time of acquisition, in viewing aspect, in imaging modality, or in parameters of imaging, e.g. focusing etc; such extra knowledge is not easily or not at all detectable in individual images. One of the ways how to obtain such extra information is the disparity analysis which compares the images by pairs, looks for their details and describes the vector field of the (x,y)-shifts between corresponding couples of details in both images of a pair.

The information, contained in the disparity maps, may be utilized directly for describing or discovering many different phenomena in the images, e.g. time-development of mutual position of objects – motion analysis, particularly in sequences of images i.e. video, for estimating of growing or diminishing of objects in temporal image sequences, and namely also for evaluating perspective changes due to different aspects of image acquisition, which is used particularly in stereo analysis of a scene, aiming at discovering the third dimension from 2D images. Such an application, including an appropriate method of disparity analysis is in detail described in [1].

Still another class of applications is opened in the area of image registration – matching of images that might be mutually shifted, rotated or generally mutually geometrically distorted. Identification of the geometric transform describing the distortion may then – particularly in complicated cases – be also based on 2D or 3D disparity maps that enable use of complicated transforms, as e.g. piecewise cubic spline deformation. This might be particularly useful in registering medical 3D tomografic data describing the scenes combined from rigid parts (e.g. bones) and flexible components – soft tissues.

Methods

Disparity analysis

A description of the used reliable disparity analysis method, based on vector angle criterion of similarity of local areas can be found in [2]. The basic idea of this approach is in finding corresponding small areas in both images of a couple and to evaluate the mutual shift of the corresponding areas between the reference image and the compared imaged. The shifts are found on a dense grid up to the density of 2 pixels per node distance, thus providing finally a disparity map – a vector-valued image overlaid on the reference image and providing the local shift information on the image area.

Finding the best position of the same detail by searching in the second (compared) image with respect to the reference image requires primarily to define a proper similarity criterion of the small areas. As pointed to in [1], the optimum criterion for this purpose turned out to be basically the angle between multidimensional vectors describing the small areas by their intensity values as the vector components. This criterion primarily is invariant to linear contrast transform between the images and proved to be robust also to nonlinear monotonous transforms. Besides that, it is relatively simple to calculate, when converted to the equivalent form of the cosine criterion (the cosine of the mentioned angle, monotonously dependent on the angle in the range of used values),

$$C_A(a,b) = \frac{ab}{|a||b|} = \frac{\sum_i a_i b_i}{\sqrt{\sum_i a_i^2}\sqrt{\sum_i b_i^2}} . \quad (1)$$

Here, CA is the similarity criterion to be used in optimisation of the shift, a and b are the vectors of the intensity values ai and bi of the compared areas. This can be – for the search of a constant area b – simplified to

$$C'_A(a,b) = \frac{ab}{|a|} . \quad (2)$$

This criterion turned out to be very robust to disturbances and noise in the images, particularly in comparison with other possible intensity based criteria – correlation or covariance, sum of squared differences etc.

The disparity analysis based on searching for similar areas must provide the disparities in a dense grid ideally reaching the halve resolution of the original images. The size of the compared areas is crucially important for the precision of the disparities: the smaller the compared areas, the better is the localisation of the disparity, but the less reliable is the found disparity, as there is increasing possibility of confusing the area with a similar one. On the other hand, larger compared areas provide sufficient amount of detail to prevent confusion in the search but then, small local differences in disparities are smoothed out. Also, searching from the very beginning in the detailed grid is computationally inefficient; more effective is to search first on a coarse grid with large compared areas and gradually decrease both parameters: the distance of nodes in the grid and the size of compared areas. However, the usual pyramidal (multiscale) approach turned out useless, as often there are not sufficient details in coarser scales. The solution of these conflicts is in s.c. layered approach consisting of gradually improving the disparity map that is described also in [2].

Disparity based registration

Registration of images requires to find a spatial transform T_α (controlled by a vector of parameters α) matching the details in the to-be-registered image A to the corresponding details of the reference image B; the images are possibly mutually shifted, rotated, scaled or even deformed in a complex non-linear way, as in the application mentioned below.

The registration means finding the transform parameter vector α such that the registration of B with the transformed image A'= T_α(A) is optimal with respect to the chosen criterion of image similarity. The transform is to be found by optimisation,

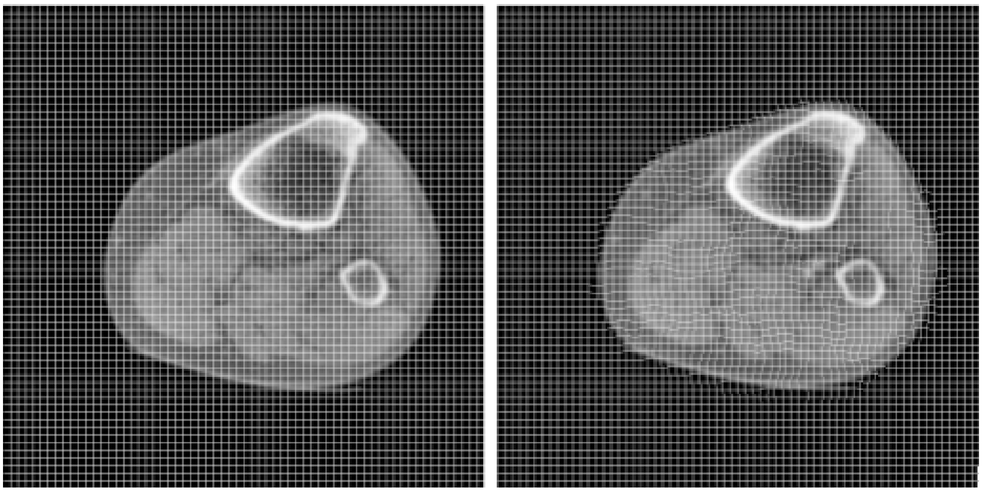
$$\alpha_0 = \arg\max_{\alpha} c\,(B(x_B),\, A'(T_\alpha(x_A))), \quad x_B, T_\alpha(x_A) \in \Omega_\alpha \quad (3)$$

where c is the global criterion of similarity between the registered images A' and B that are defined on their respective pixel sets X_A andX_B, Ω is the spatial intersection of both images.
The problem is complicated by the fact that the areas of compared images mostly do not match completely but only a partial intersection Wa (moreover dependent on the parameter vector a changing during the optimisation) is in fact registered. Here, the similarity criterion takes into account the complete cross-sectional area; an example might be a global mutual-information based criterion.
Instead of using a formally global criterion c, it is possible to use just local criteria of similarity if the transform is formulated in a piece-vice manner. Ultimately, just very small local areas of the size in the order of single or a few pixels may be considered and in this case, simple local transforms can be used based only on local shifts in both (in 2D case) or in all three (in 3D case) directions. Then the disparity map may be used as the source of information on the mutual image distortion, at the possibly most detailed level.
This new reformulation enables to register even images that are mutually distorted in a very complex way (naturally excluding any folding), possibly substantially differing in the properties of the deformation in different parts of the image. This is e.g. the case, when dealing with medical image data containing both rigid structures like bones, semi-rigid ones like cartilages and soft tissues like muscles and fat, possibly locally compressed or otherwise deformed.

Applications in the medical 3D image registration

The problem suitable for application of the disparity-based registration formulation is to register the 3D CT data (data provided by the X-ray computed tomography) for angiographic purposes.

Figure 1. To be registered image data – reference image (left), to-be-registered image (right). The images are 2D slices of 3D CT data of lower extremities, the found corresponding points are marked by the knots of the grids, thus the disparity map is given by the values of the respective 2D shifts. The project concerns 3D registration, 2D representation is used for demonstration purposes only.



The image data provided by a cooperating medical institution concerned the lower extremities; the aim is the classical image subtraction of the base (pre-contrast) image from the image data obtained after filling vessels with a contrast agent. As the result of subtraction, only the contrasted vessels should be visible while all the other structures should be removed, which is only feasible when the registration is extremely precise, in the range of single pixel or even with sub-pixel precision.
This task is complicated by the complex way in which both sets of data may be mutually geometrically distorted. Though the distortion is usually only in the range of several pixels, simple registering transforms and usual approaches are insufficiently flexible and cannot be used as even small discrepancies lead to extremely visible and disturbing artefacts. The above suggested approach, on the other hand, enables much more precise registration. An example of the images to be registered (2D corresponding slices from the pre- and post-contrast 3D data) marked with a grid

visualising the found corresponding points as the knots of the grids, is shown on Figure 1.

Discussion and conclusions

The paper discusses a newly suggested approach for registration based on the information contained in the 2D and 3D disparity maps that enables to treat the cases of spatial registration under complex mutual distortion of the to-be-registered image data. The disparity map then provides the necessary information for designing the proper piecewise-formulated geometrical transform precisely matching the corresponding details in the registered data. The method is presently tested in frame of a project supported by a large industrial firm and aiming at improving the angiographic CT imaging and vessel structure evaluation. The preliminary results will be shortly published in [3].
From the point of view of engineering education, this methodology proved to be a suitable core for an interesting group project of doctoral students.

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