Voxel similarity based automatic image registration

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Related projects:
  - Transforming CT studies of the pelvic region to a common reference frame [3]

Lifetime from: 1999
Lifetime to: 2003
Short description: An automatic registration method utilizing mutual information and its various medical and neutron tomography applications.

Description:
We proposed a fast, fully automatic registration algorithm that is capable of solving unimodality or multimodality registration problems in 2D or 3D. Many similarity measures were proposed in the past decade. We chose the measures based on the mutual information of the images proposed by Collignon et al. and Viola and Wells, and on the normalized mutual information of the images proposed by Studholme et al.

To speed up the registration process and to avoid falling in local minima during search, we used the Gauss pyramid representation of the images. The search starts at the coarsest level. When an optimal result is reached, this is used to initialize the next, finest level. We use Powell’s direction set, iterative, nonlinear optimization algorithm to find the optimum of the similarity measure. This method requires evaluating the similarity measure value for given transformation parameters only, no gradient or other information is necessary. The most time consuming part of the process is the execution of the transformation. We utilized many optimizations, e.g., multiplications were superseded by summations, mutual information was reformulated for less computations and a look-up table was used to get logarithmic values.

Vanderbilt validation
To evaluate our registration method, we joined the Retrospective Registration Evaluation Project of Vanderbilt University, USA in 1999. The objective of that project was to perform blinded evaluation of retrospective image registration techniques using a prospective, marker-based registration method as a gold standard.

Two registration tasks were evaluated: CT to MR and PET to MR, and these tasks were broken into subtasks according to the type of MR and to whether or not the MR image was corrected (rectified) for geometrical distortion. The image data set of nine patients were used, seven of which contained both CT and MR, and seven with both PET and MR.

Before the evaluation of our results, we visually inspected the quality of registration. When the normalized version of the mutual information (NMI) was used, all registration results were visually acceptable. In case of mutual information (MI), the results were visibly misregistered for four image pairs of PET–MR problems. In spite of these clear misregistrations, all results were submitted for
evaluation to Vanderbilt University.

The results show that in case of CT to MR registration task, both of our methods produce acceptable results. Our MI method produces good, our NMI method average results. For PET–MR problems, the MI method tends to fail (four failures out of 35 cases), and that’s why it produces average results. The NMI method gives stable results and ranks high among the competing algorithms. The running time was about 30–120 seconds on a 800 MHz Pentium-III PC. Figure 1 shows two registration results.
Figure 1. MR-CT (top row) and MR-PET (bottom row) registration problems, before (left column) and after (right column) registration.

Application in neutron tomography

The registration method was used in an interesting, non-medical problem. Neutron radiography provides more contrasted images than conventional X-ray based techniques when examining the inner parts of objects made from iron, copper or aluminium. As it passes through the objects, the neutron ray is absorbed to some extent. The remaining intensity of the ray is measured by an imaging plate, thus we can get the projected image of the object. By rotating the object, a series of 2D projections is produced from which the 3D model of the object can be calculated using tomographic methods.

The way the images are taken introduces geometric differences between the consecutive projections. It means that the same projection directions from the source might pass the imaging plate at different pixel locations. Such geometric differences can degrade the result of the reconstruction. Image registration is applied to recover these geometric differences.

The main reason of error is the fact that the removing and reinserting the imaging plate can cause translational and rotational differences. To eliminate the rotational invariance, artificial markers are affixed in front of the imaging plate, the projections of which are visible in the top, bottom, left and right hand side of the images.

We used the 2D version of our method based on normalized mutual information. It is assumed that a rigid-body transformation (translation along the axes and rotation about the center of the image) can align the images. Although the algorithm is fully automatic, a pre-processing step is necessary. The center region of the images, where the projection of the object is visible, must be masked out and the similarity measure is evaluated only outside of it. One of the projection images is selected as the reference image and the others, including the open beam projection image, are registered against it one by one.

Visual inspection confirmed that the markers aligned well after registration (Figures 2 and 3) and that the reconstruction using the registered images produced 3D images of better quality.
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Figure 2. Projection images before (left) and after (right) registration.

Figure 3. Accumulated images of the motion of the marker on the center right hand side before (left) and after (right) registration.

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