2D-3D Rigid Body Registration of X-ray Fluoroscopic and CT Images

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The Problem: Registration of two datasets is the process of identifying a geometrical transformation that locates the coordinate system of one in that of the other. Rigid body registration restricts the searched transformation to be a combination of translations and rotations which are sufficient to describe the movement of solid objects.

We propose to register CT volumetric datasets to corresponding 2D X-ray fluoroscopic images. As a single 2D image, in practice, does not convey sufficient information about the spatial location of the imaged object, we require two projection images to achieve our task. We assume that the two imaging views are related by a known transformation.

The main challenges of the problem lie in identifying a similarity measure that can quantify the quality of the alignment between the images and in defining a procedure to modify and refine current estimates of the transformation parameters in a way that the similarity score is optimized.

Motivation: Although 2D images lack significant information that is present in 3D modalities, they might be conveniently and efficiently used to record details about the most current state of the imaged object. The most amount of information can be gained about the changes recorded by the 2D modalities and the detailed 3D model if we fuse the information provided by both of them. In order to achieve the proper spatial alignment of the different components, it is necessary to determine their relative position and orientation.

Previous Work: Alignment methods that have been introduced to achieve the 2D-3D rigid-body registration task might be best distinguished based upon the similarity function and the optimization techniques they use. Feature-based similarity measures rely on the presence and identification of natural landmarks or fiducial markers in the input datasets in order to determine the best alignment. Intensity-based measures operate on the pixel or voxel intensities directly. They calculate various statistics using the raw intensity values of the inputs which are then compared in the images to be aligned. Though the number of points to be registered is much greater than in the case of the feature-based methods, no feature extraction step is required.

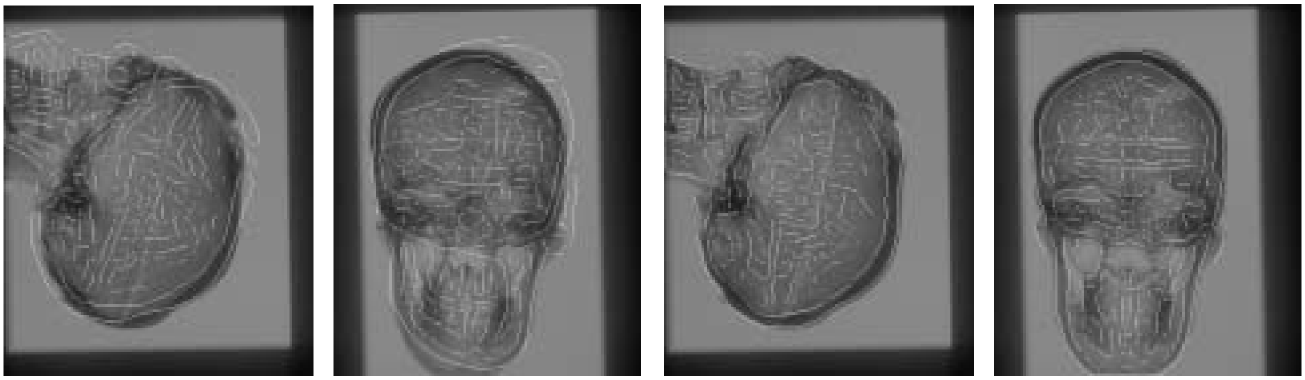
Optimization procedures are responsible for modifying the current parameter estimates in a way that the preferred similarity function eventually takes on its (local) extremum. The choice of such a method largely depends on timing constraints and computational resources.

Approach: We propose an intensity-based registration algorithm using an information theoretic objective function, mutual information (MI) [1, 3], to establish the proper alignment of the input datasets. For optimization purposes, we compare the performance of the non-gradient Powell method and two slightly different versions of a stochastic gradient ascent strategy: one using a sparsely sampled histogramming approach and the other Parzen windowing to carry out probability density approximation.

In order to compare the multi-dimensional images, with the current estimate of the transformation parameters we create a simulated version of the 2D acquisitions. A pair of such Digitally Reconstructed Radiographs (DRRs) is compared to the observed X-ray images.

Our main contribution lies in adopting a stochastic approximation scheme successfully applied in 3D-3D registration problems ([2, 3]) to the 2D-3D scenario, which obviates the need for the generation of full DRRs at each iteration of pose optimization. This facilitates a considerable savings in computation expense. We also introduce a new probability density estimator for image intensities via sparse histogramming, derive gradient estimates for the density measures required by the maximization procedure and introduce the framework for a multiresolution strategy to the problem.

Figure 1 displays registration results of an experiment on X-ray and CT acquisitions of a skull dataset. Contours of the DRR images created by the output of the registration algorithm are overlaid on the observed fluoro images.



(a) (b) (c) (d)

Figure 1: Registration results of an experiment on X-ray and CT acquisitions of a skull dataset. Contours of the DRR images created by the output of the registration algorithm are overlaid on the observed fluoro images. (a)-(b) DRR contours created using the initial transformation estimate; (c)-(d) DRR contours created using the transformation estimate resulting from the registration process.

Impact: We have focused our attention on examining applications in the medical field that could benefit from a reliable (and efficient) solution to the 2D-3D registration problem. Introducing highly accurate pre-operative 3D information about the examined anatomy into the operating room, where normally only lower dimensional images can be acquired, has proved to be crucial both in neuroradiology and orthopedics. As an example, the proposed 2D-3D rigid body registration technique could be used to assist in monitoring the path of a catheter led from below the waist to the head through blood vessels (e.g., 3D Roadmapping) and in orthopedics it could aid in verifying of the location and position of the examined organ and surgical tools during an intervention (e.g., total hip replacement, revision operations).

Future Work: We plan to extend our investigation of the 2D-3D registration problem by examining whether the registration results could be improved by an increased number of interventional images. We are also interested in eliminating distortions from the X-ray fluoroscopic images during the pre-processing step and in generalizing some of our assumptions made when formulating the MI-based similarity function.

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