Fast coarse-to-fine elastic registration of medical data

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Purpose

In this work, we present a new approach for the non-rigid registration of medical data (figure 1). The presented technique can also be applied for model-based segmentation.

Rigid Registration

Point-based rigid registration is basically the transformation (rotation and translation) between data points and model points (figure 2). This transformation is known as 4 (resp. 6) degrees of freedom for 2D (resp. 3D) data and can be computed by minimizing the following equation:

$$\Gamma(\mathbf{R},\mathbf{t}) = \min \left\| \mathbf{R} \cdot \mathbf{p}_i + \mathbf{t} - \mathbf{q}_i \right\|$$

tau transformation
R rotation matrix
t translation matrix
p_i data points
q_i model points

More complex rigid registrations include similarities (rotation, translation and homothety) or affine transformation with 12 DoF. for 3D data:

$$\Gamma(\mathbf{R},\mathbf{t}) = \min \left\| \mathbf{A} \cdot \mathbf{p}_i - \mathbf{q}_i \right\|$$

tau transformation
A affine homogenous matrix
p_i data points
q_i model points

Rigid registrations are usually solved using the iterative closest point algorithm (ICP).

Non-Rigid Registration

3D non-rigid registration or free-form deformations can be achieved using for example a B-Spline technique. In this case, the number of degrees of freedom depends on its control grid density and the number of DoF can dramatically increase.

Proposed Solution

The global registration process first starts with a coarse registration including a rigid followed by an affine transformation. The intermediate result is refined using a non-rigid deformation based on a deformable model technique. The model consists of a simplified skeleton (medial axis), control points and a skin (figures 3 and 4). The control points are located on the extremities of the medial axis and at its intersections. A "skin" connects the skeleton with the contour/surface. Raw deformations can be achieved by modifying the control points positions and strengths. Finally, the local motion is realized by a free-form deformation based on active contours and solved using dynamic programming (figure 5).

Contrary to a B-Spline registration technique, the advantage of the presented approach is a reduced number of extra DoF and to preserve the model during the whole deformation process, allowing improving the convergence, accuracy and speed of the registration.

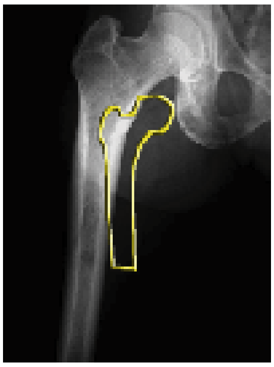

Figure 1: 2D case problematic. The model in yellow should be registered with the femur on the X-ray image (data).

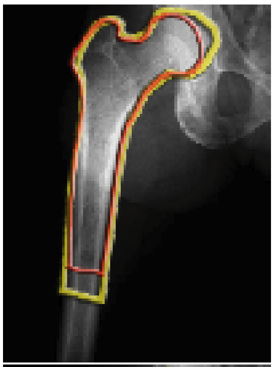

Figure 2: The contour in yellow represent the result after a rigid registration (rotation and translation), while the "correct" contour is overlaid in red. Note that this result can be improved by using an affine registration.

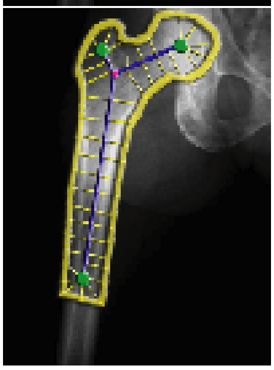

Figure 3: The deformable model is composed of a simplified medial axis or skeleton (blue), control points (green, purple) and a skin (yellow). The displacement of a control points will locally modify the shape of the contour.

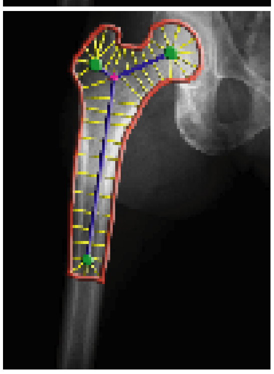

Figure 4: Deformable model after the non-rigid deformation. Note that local registration is still not perfect. Active contours should be used to find the exact position of the data.

Figure 5: Partial unwarpped representation of the femur during dynamic programming.