Registration of 2D Deformable Models to 2D CT Images

DING Feng

School of Computing
National University of Singapore

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Outline

Problem Definition

Algorithm

Results and Discussion

Assumptions

- The input CT images always contain the full view of cross section image of the abdomen.
- The anatomic structures are similar in different target images and reference image.
- The background of the input CT images (outside of the body contour) is mainly in black.

Inputs

- Let $M = \{p_i\}$ denote a set of control points on the reference contour.
- Let $S(p)$ denote the curvature at point p.
- Let $C = \{q_j\}$ denote the set of edge points in the image, which include edge points along the contour of the soft tissue and possibly other noise points, such as edge points along the contour of other soft tissues, noise edges, etc.

Output

- The extracted contour is represented by a deformed version of M. Denote it as $M' = \{p'_i\}$.
- Final contours are interpolated based on these control points.

Problem Formulation

Define f as a correspondence function from M to C, that is, $f(p_i) \in C$. Let $D(M)$ denote a deformation function of M by moving the points $p_i \in M$ to new locations $p_i' = D(p_i)$. Let T denote a transformation function before deformation. Then, the problem is to find the T, D and f that minimize the total error E,

$$E = (1 - \alpha)E_p + \alpha E_s \tag{1}$$

where E_p corresponds to the edge point error:

$$E_p = \sum_i ||D(T(p_i)) - f(p_i)||^2 \tag{2}$$

and E_s corresponds to the shape difference:

$$E_s = \sum_i ||S(p_i) - S(D(T(p_i)))||^2 \tag{3}$$

Problem Formulation - Cont'd

The error function E can be further formulated as:

$$E = \frac{1}{|m|}\left[(1-\alpha)\sum_{p_i \in m} ||D(T(p_i)) - f(p_i)||^2 + \alpha \sum_{p_i \in m} ||S(p_i) - S(D(T(p_i)))||^2\right] \quad (4)$$

where $m \subseteq M$ $s.t.$ $||D(T(p_i)) - f(p_i)|| < \Gamma$, for an appropriate predefined threshold Γ, and $\alpha \in [0,1]$.α may be different at each iteration *w.r.t.* the ponderance of shape information during deformation.

Algorithm

- Basic ideas: two steps.
    - Initialization: transformation.
    - Refinement: GVF snake.

Initialization

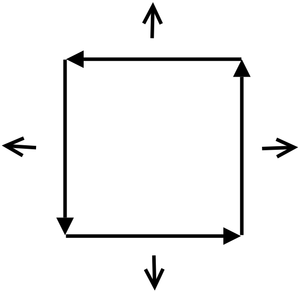
- The results of deformable models depend on the initial configuration of the contours.
- A good `initialization` is to pull the model contour to somewhere close to the target soft tissue.
- Transformation
  - Global affine transformation (whole body contour).
  - Local affine transformation (soft tissue contours).

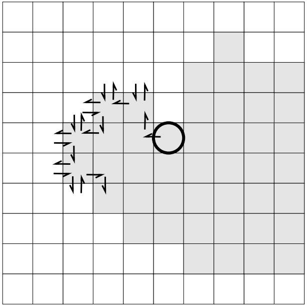
Global Transformation

- Manually delineate the outer body contour in the reference image.
- Use contour tracing to get the outer body contour in the target image.
- Perform 2-D and 2-D registration with unknown correspondence on reference body contour and input body contour using *Iterative Closest Point* algorithm.

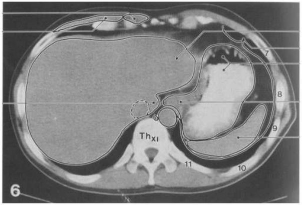
Global Transformation

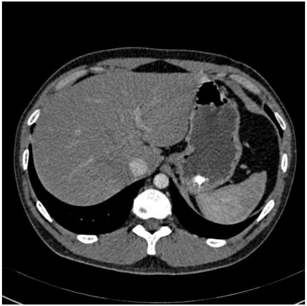
- Contour tracing.





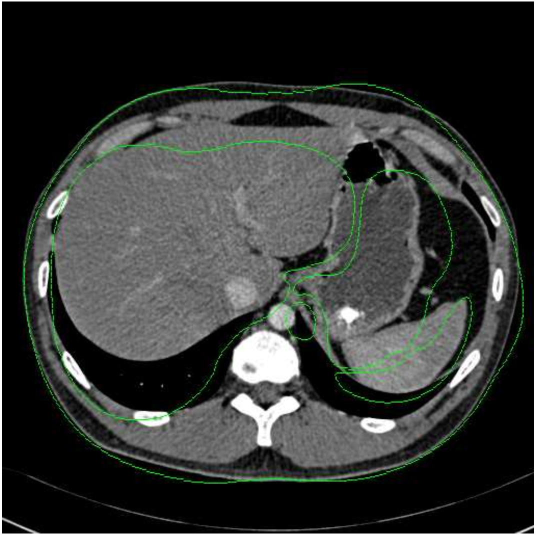
Global Transformation





- After registration, the transformation from the reference image to the target image is known.
- Pose this transformation on the model soft tissue contours.

Global Transformation



Initialization - Local Transformation

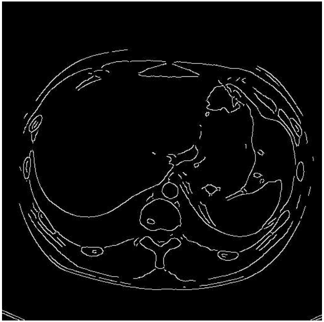
- Model soft tissue contours are not in "good" places.
- "Good" - close to the real contour in the target images.
- May fail the refinement procedure.
- Improvement - local transformation.

Local Transformation

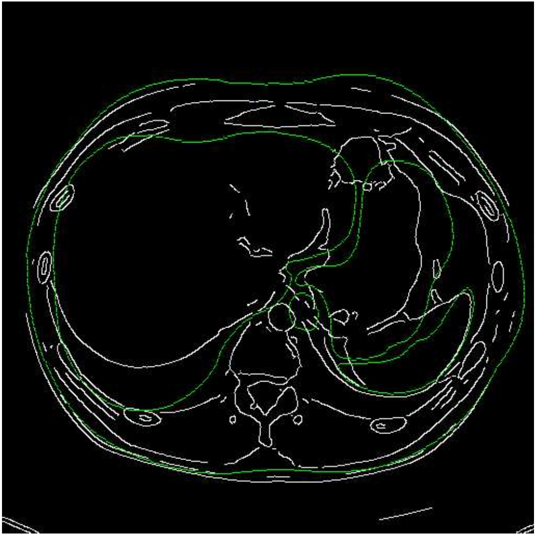
- Four major soft tissues.
- Separate into two groups based on the size of the soft tissues.
  - Group 1 - Liver, stomach and spleen.
  - Group 2 - Thoracic aorta.
- For group 1, the contours after global transformation are "roughly" close to the corresponding soft tissues.
- "Roughly" - Centroid of the model contours are inside of the corresponding soft tissues.

Local Transformation

- Group 1 - liver for example.
- Idea: Use the available edge and gradient information as much as possible.
- Edge map of the target image.



Local Transformation



Local Transformation

- Find corresponding points.
- Move model contour points along the contour normal to find edge points. If not found, the original points on the model contour will be picked.
- May find multiple edge points in the searching range, put these points in a short list.
- Compute N points gradient distribution along the normal in the reference image.
- Compute N points gradient distribution along the normal in the target image for the short-listed points.
- Pick the point with minimum gradient distribution distance.

Local Transformation

- Shoot rays from the centroid the model contour to those points picked in the last step.
- Filter out “unreasonable” corresponding points.
- “unreasonable” - too many “black” or “white” points along the path of the ray.
- Some points on the model contours and their corresponding points in the target image are obtained.

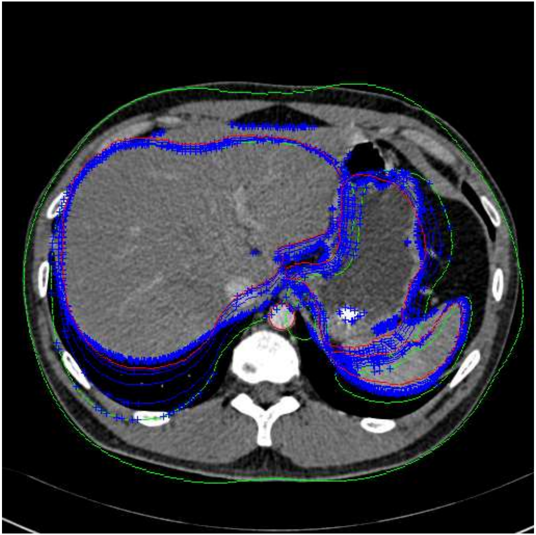
Local Transformation

- Compute Affine transformation matrix.
- Transform the model contour with the Affine transformation matrix.
- Compute error function - sum of Euclidean distance between two sets of points.
- Make the transformed contour as the model contour.
- Iteratively repeat these steps until the error is small enough.

Local Transformation

- Group 2 - thoracic aorta
- Idea: Use a circle with similar size to represent its initial contour, and search in a window of the *edge map* to find the "best fit".
- Place an initial circle in the centroid of the model thoracic aorta contour.
- For each point on the circle, find the closest point in the edge map with in certain range, compute the distance (error) and sum up.
- Move the circle in a search window, and repeat last step until whole search window is traversed.
- Select the circle with the minimum error as the model contour.

Local Transformation



Refinement

- Feed the contours obtained in the initialization step to GVF snake program.
- Adjust α and β values which control the elasticity and rigidity of the snake.
- Iteratively deform the snake.

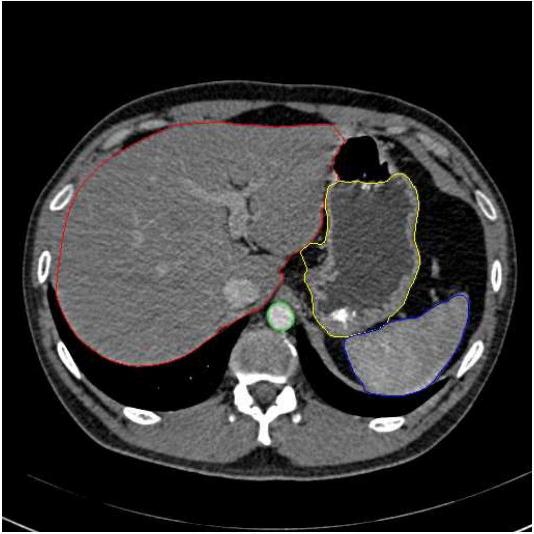
Results

- Use the provided five images as input images.
- Run the algorithm to get the final contours.
- Manually extract the soft tissue contours in the five images.
- Compute the similarity index between contours extracted by program and by hand.
- Similarity Index:

$$S = 2\frac{|A_1 \cap A_2|}{|A_1| + |A_2|} \tag{5}$$

where A_1 and A_2 represent two corresponding tissues.

Results

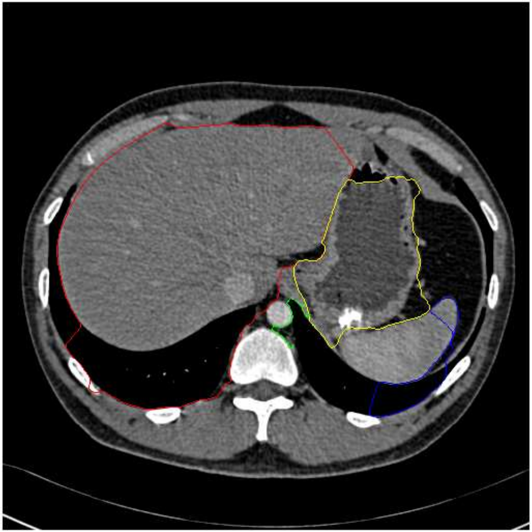


Similarity Index

Table: Segmentation similarity index.

	Liver	Stomach	Spleen	Thoracic Aorta
Target Image 0	0.973	0.907	0.923	0.896
Target Image 1	0.968	0.874	0.921	0.888
Target Image 2	0.973	0.864	0.935	0.908
Target Image 3	0.962	0.839	0.946	0.886
Target Image 4	0.968	0.868	0.923	0.907

Results Without Initial Local Transformation



Further Improvement

- Need good model, similar to the target images.
- Contours are easily attracted to “noise” edges, add some shape constraint.