ISTITUTO ITALIANO DI TECNOLOGIA
PATTERN ANALYSIS AND COMPUTER VISION

Weakly Supervised Geodesic Segmentation of Egyptian Mummy CT Scans

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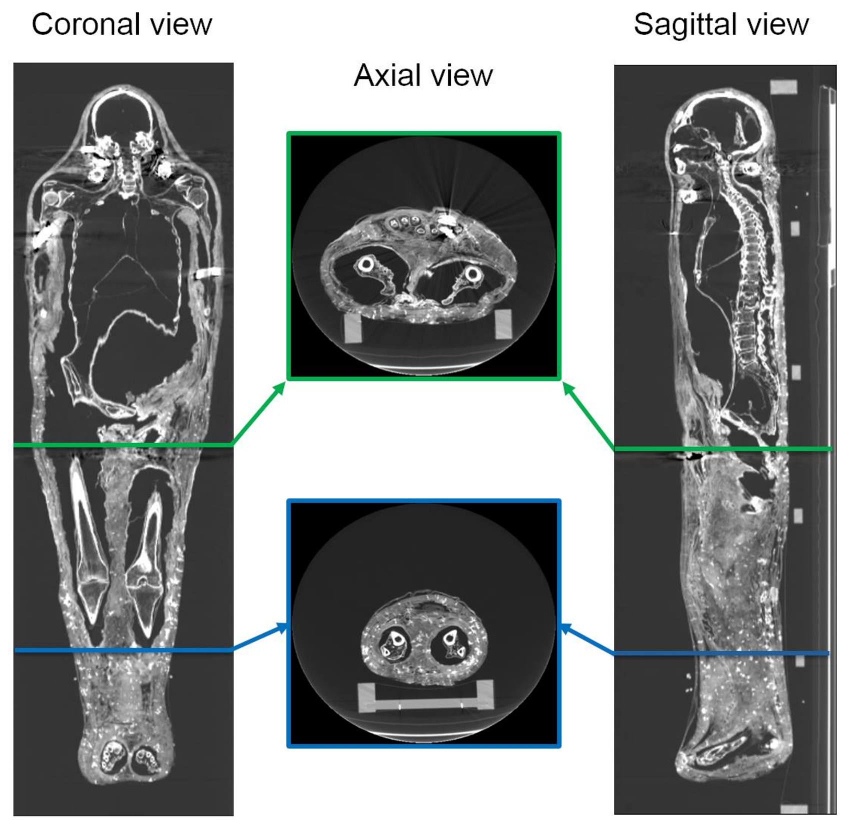
Abstract

Automatic segmentation of ancient Egyptian mummies CT scans is a complex problem due to the lack of annotated data for the different semantic regions to segment, thus discouraging the use of strongly supervised approaches.

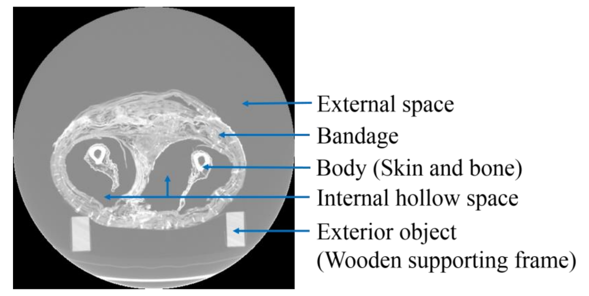
We propose a weakly supervised and efficient interactive segmentation method to solve this challenging problem, using limited supervision in the form of scribbles drawn by the user.

The efficiency of the proposed method is demonstrated using visualizations and validated through quantitative measures and qualitative unwrapping of the mummy.

Overview



CT scans are standard data used in medical image processing, but the methods proposed in the literature are not suitable for 3D mummy CT scans segmentation. In fact, mummy's tissues do not have the same characteristics as typical medical data.



Challenges:

- Scattering due to the presence of metal (*jewels*);
- Varying structure of the supporting frame;
- Density values of bandage and mummy body are in the same range.

Our contribution: we propose an efficient interactive segmentation method, with limited user interaction needed. To the best of our knowledge, this is the first work attempting to solve the problem of mummy 3D CT scan segmentation by a weakly supervised method.

Pipeline

Step 0 - Pre-processing

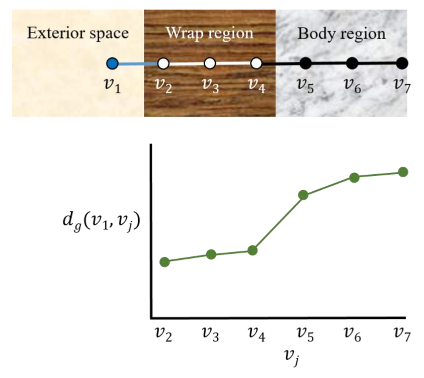
In the pre-processing stage we aim at segmenting all the elements which are not related to the wrapped mummy's body, separating the External Space, the Exterior objects and the mummy's metals. We use histogram voxel analysis, template matching, Hough transformation and voxels thresholding grouping the connected components.

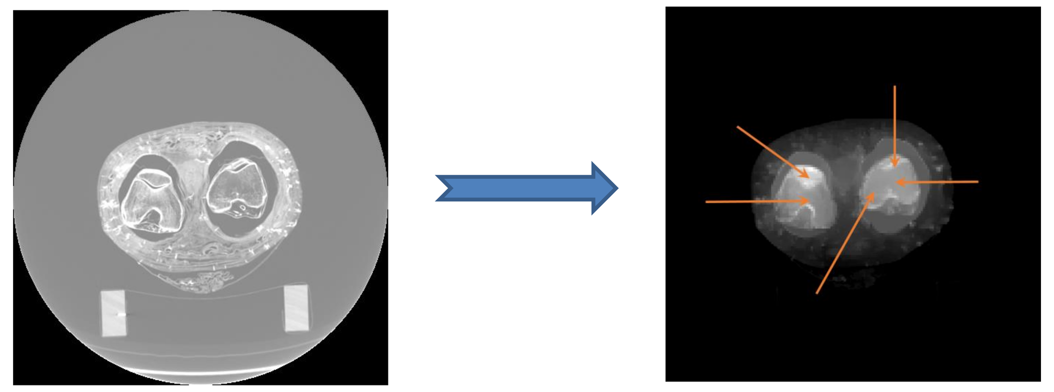
Step 1 – Geodesic segmentation

Bandage and mummy's body have a very similar radiodensity and it is not uncommon that two adjacent and similar voxels belong to the two different segments For separating them, we can leverage the data structure of the mummy's CT scan, since Body is wrapped in Bandage. We decided to calculate geodesic distance from the exterior region to the unclassified voxels, defined as the cumulative pairwise distance along the shortest path connecting two voxels.

Patches with smaller geodesic distances constitute the bandage and patches with larger geodesic distances constitute the body region.

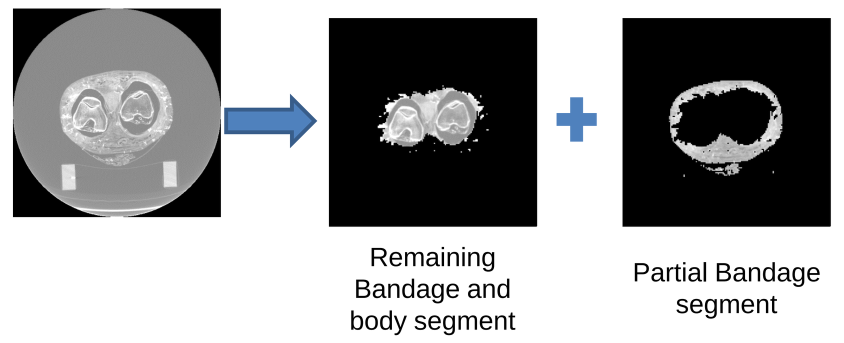
$$d_g(v_i, v_j) = \min_{\mathcal{P}^{ij} \in \mathbb{P}^{ij}} \sum_{(v_k, v_{k+1}) \in \mathcal{P}^{ij}} d(v_k, v_{k+1})$$

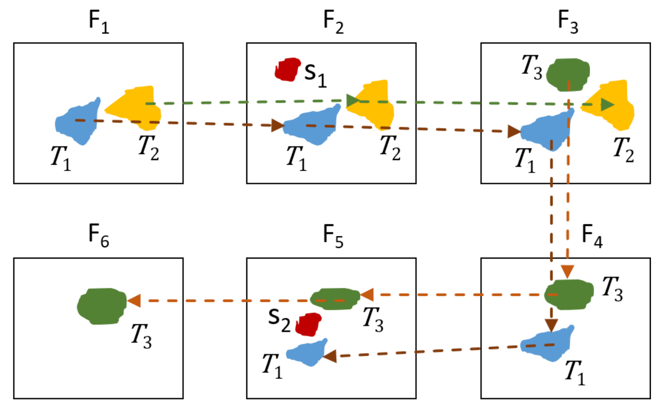




Step 2 – GrabCut segmentation and tracking

We improve body/bandage segmentation by applying GrabCut segmentation initialized with the results obtained using Geodesic segmentation. Finally, we use tracking of the valid segments for connecting the segments calculated in every single slice through volume level processing of data, ensuring information propagation and thus yielding more accurate segmentation results.

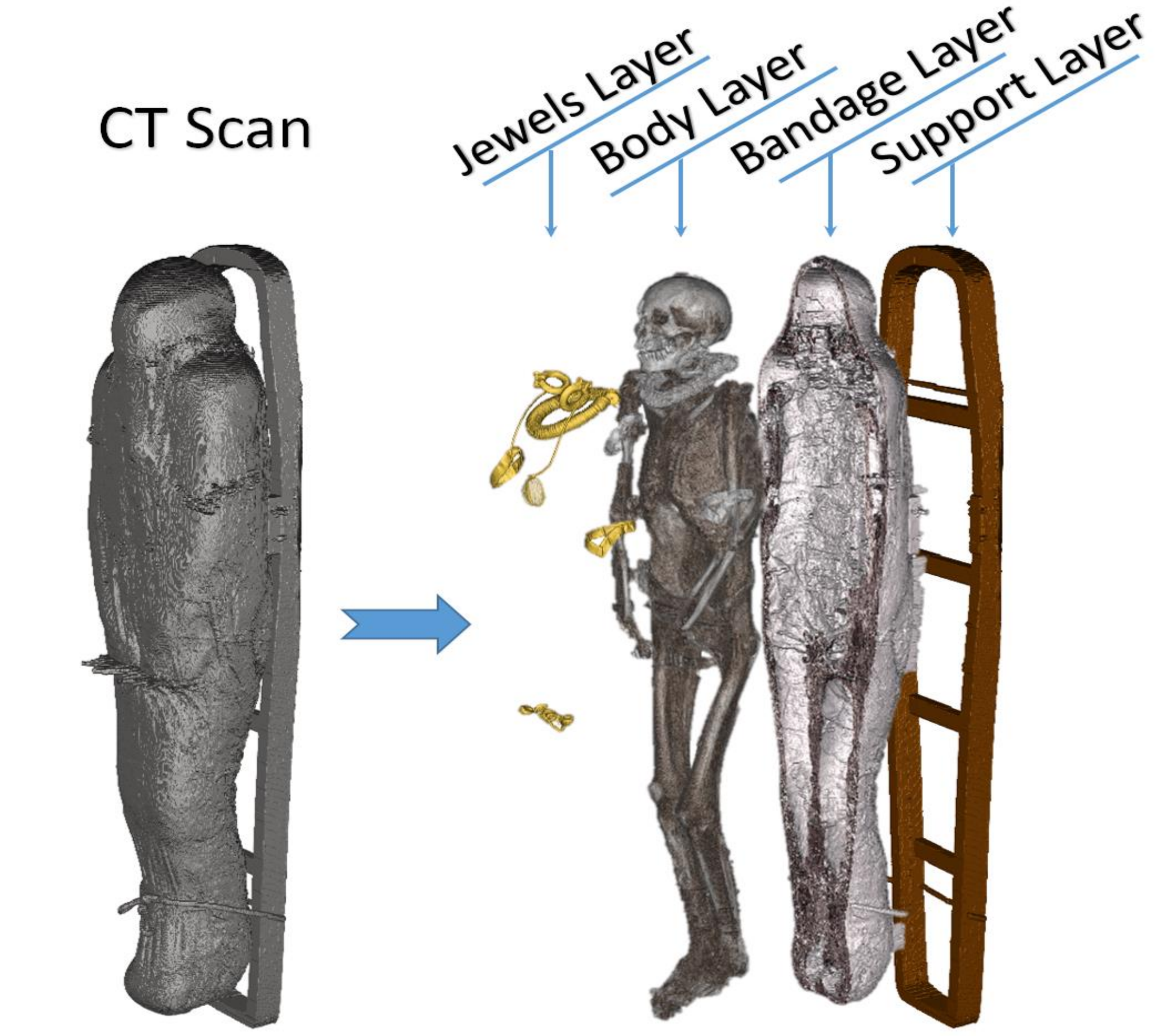




$$T_i^{(k+1)} = \arg \max_{s_j \in R_b^{(k+1)}} \Phi(H_i^{(k)}, s_j)$$

Results

Qualitative Results



Quantitative Results

In the absence of a large number of subjects for validating the proposed method, we generated additional CT scans by transforming the original scan using thin-plate splines [1] for evaluation.
We compared the average IOU score of our proposed method with standard interactive segmentation methods:

	Proposed method	GrabCut segmentation [2]	Saliency detection [3]	Graph Cut segmentation [4]	Video object segmentation [5]
IOU	0.81	0.50	0.46	0.42	0.24

We performed an ablation study on the different available and generated subjects, in order to assess the effectiveness of the tracking algorithm:

	Original	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6
IOU without tracking	0.79	0.80	0.81	0.80	0.80	0.80	0.80
IOU with tracking	0.81	0.81	0.81	0.82	0.81	0.82	0.82

References:

[1] F. L. Bookstein, "Principal warps: thin-plate splines and the decomposition of deformations," IEEE Trans. PAMI, vol. 11, no. 6, pp. 567–585, June 1989.
[2] C. Rother, V. Kolmogorov, and A. Blake, ""GrabCut" interactive foreground extraction using iterated graph cuts," ACM Trans. Graph., vol. 23, no. 3, pp. 309–314, 2004.
[3] W. Zhu, S. Liang, Y. Wei, and J. Sun, "Saliency optimization from robust background detection," in Proc. IEEE CVPR, 2014, pp. 2814–2821.
[4] J. Borovec, J. ˇ Svihl´ık, J. Kybic, and D. Habart, "Supervised and unsupervised segmentation using superpixels, model estimation, and graph cut," Journal of Electron. Imaging, vol. 26, no. 6, pp. 1–17, 2017.
[5] B. A. Griffin and J. J. Corso, "Tukey-inspired video object segmentation," in Proc. IEEE WACV, 2019.