

Segmenting the Dead Sea Scroll Fragment Images

The Dead Sea Scrolls comprise close to a thousand ancient manuscripts discovered near Qumran between 1947 and 1956, primarily written on parchment and papyrus and dating from the third century BCE to the first century CE. Their texts hold significant historical, religious, and linguistic value, including some of the earliest Hebrew Bible manuscripts.

Since 2011, the Israel Antiquities Authority has been digitizing the scroll fragments, both recto and verso sides, creating high-resolution images using twelve wavelengths across visible and infrared spectra. Despite computational advantages of a blue background, black was chosen for minimal reflectivity. Each image includes calibration objects whose placement varies between fragments.

Accurate segmentation of the fragments in these images is essential for comparing historical and modern images, facilitating computational analyses, letter recognition, paleographic studies, and testing digital hypotheses about fragment joins. Segmentation challenges include variable calibration object placement, the similarity between background and ink colors, and rice paper used for conservation.

We have created the publicly available "Qumran Segmentation Dataset," consisting of 138 fragment images (99 training, 20 validation, and 19 testing), as a benchmark for evaluating segmentation methods. Fragments were randomly selected without manuscript overlap to ensure generalizability. Each image includes bounding box annotations for the calibration objects. The annotations for recto images in the test set are provided as well-known text (WKT) polygons, offering precise contour information.

Our own segmentation method uses faster R-CNN to detect calibration objects, followed by the computation of an alignment matrix of recto and verso images using SIFT feature detection and RANSAC-based feature matching.

We threshold grayscale infrared images, which provide higher contrast between the fragment and the background, using a dynamic lower bound calculated from the average intensity of dark pixels plus a buffer. The resulting masks for the recto and verso sides are aligned and combined using the alignment matrix. This initial mask includes both the fragment (ink and parchment) and the surrounding rice paper regions, separating them from the background and parchment holes.

We then segment the rice paper using HSV color space thresholds, refined by morphological operations with an elliptical kernel, leveraging the consistent pixel density of the images. A rice paper mask is subtracted from the initial mask to produce the final fragment segmentation. Evaluation metrics show a mean IoU of 97%, precision of 98%, and recall of 99% at the pixel level.