An Automatic Algorithm for Skin Surface Extraction from MR scans

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Purpose

The purpose of this project was to develop an algorithm that extracts skin surface from MR scans of human head with no or minimal human interaction. The goal is to have a simple and fast algorithm that can be practically applied, e.g. in surgical navigation systems.

Introduction

Skin extraction algorithms are either complex (see [1]) or require human correction and refinement (see [2], [4]). The algorithm we present is between the two cases – it is rather simple and requires minimal human interaction, with capability to be fully automated.

Typical problems in extracting the skin surface are noise, "body openings" and surrounding (undesired) structures. The "body openings", e.g. ear channels, cause problems since the skin surface can "leak" through them inside the head. Due to the aliasing at dataset reconstruction, there is often a repetition of bottom structures of head at the top of the dataset, making an undesired object. The algorithm is based on a series of morphological operations that overcome these problems.

Methods and Results

Since the method involves morphological operations, to insure isotropic behavior of the algorithm we first isotropicly resample the dataset (e.g. if the voxel size was originally 1 by 1 by 1.5 mm, after resampling the voxel size will be 1 mm^3). After the algorithm is finished we resample the result back, so that the obtained segmentation map corresponds to the original dataset.

The only parameter that needs to be set is the threshold, which is used to convert the grayscale dataset to a binary one, i.e., roughly speaking, to separate the background from the rest. We set the threshold manually, which takes less than a minute, although it could be extracted in an automatic fashion, e.g. using the approach suggested in [3].

The next step is to extract the largest connected object in the binary 3D dataset (we use 6-connectivity). Typically, there are many separated binary objects, mainly due to noise, but also due to the surrounding structures explained above. One can reliably assume that the head will produce the largest connected object, since this assumption can be violated only under extreme conditions. If that datasets are very noisy, so that the objects that would otherwise be separated are now connected, one might want to run the connection-breaking algorithm (see [4]) before extracting the largest connected object.

Now, the extracted binary object has empty interiors, and it has certain number of small holes (typically ear channels, sometimes eyes). The next step closes the holes and fills the empty interiors, making the object simply connected. The idea is to dilate the object until the holes are closed, then fill the interiors, and erode back the same number of times the object was dilated. It is easily to determine how many times one needs to dilate the object since these holes are not more than a few millimeters in diameter, and the voxel size is know. The noise is removed using a nonlinear filtering motivated by the median filter. Any object voxel surrounded by less than 10 object voxels is removed (set to be a non-object voxel), and any non-object voxel surrounded by less than 10 non-object is set to be an object voxel. Note that any voxel is surrounded by 26 voxels. This operation is iteratively repeated until there are no voxels to be converted. It successfully removes most of the noise, while preserving most of the high frequencies of the surface (it outperforms linear filtering noise removal methods).

Finally, a triangularized surface is generated from the binary object using [5]. The skin segmentation algorithm runs about one minute (for a 256 by 256 by 124 MRI dataset) on SGI Octane R10000 machine, which is acceptable for most applications.

The algorithm was tested on 10 datasets, and no leakage or non-filled head interiors were detected, all surrounding objects were successfully removed, while having the average error within 1 mm. A typical algorithm output is shown in figures 1 and 2. One can see that, at least for this example, the goals have been accomplished. A few demos can be seen at http://noodle.med.yale.edu/~oskar/movies/movies.html.

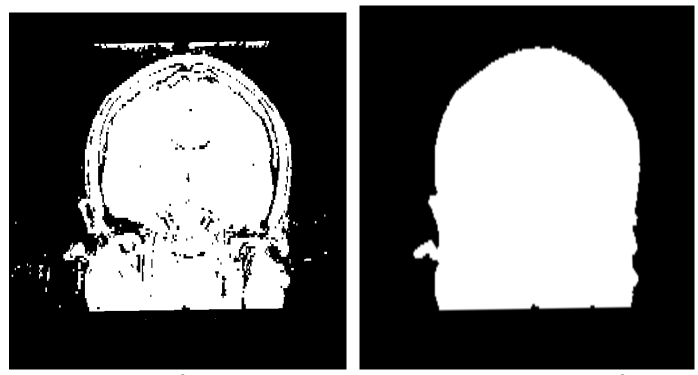

Figure 1. The left image shows a thresholded coronal slice of an MRI dataset. One can see noise, empty interiors, holes (ear channels) and surrounding objects (the top artifacts). The right image is the same slice of the segmentation map after the algorithm has been run. The noise, holes, interior regions and surrounding objects have been eliminated.

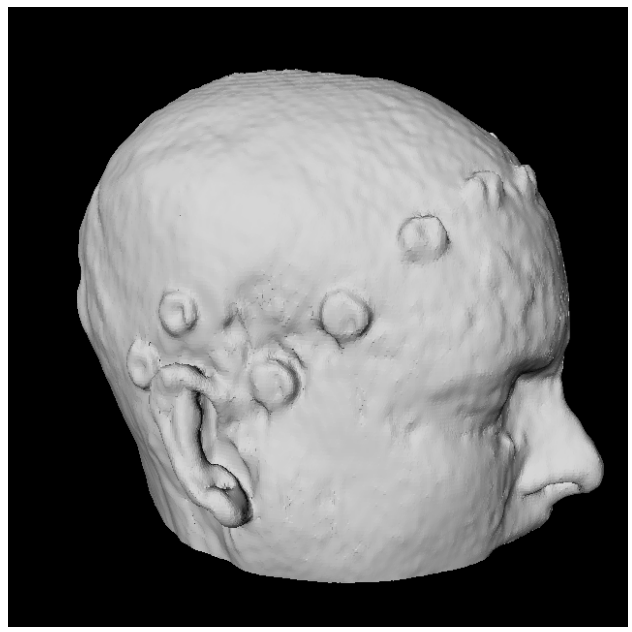

Figure 2. Surface rendered skin extracted by the proposed algorithm. One can see the fiducial markers (used for registration purposes in surgical navigation systems) on the skin surface. Most of the noise is removed while not significantly affecting the surface regions of higher curvature.

Discussion

We have developed an automatic algorithm for skin surface extraction. Its speed, performance and minimal human interaction make it directly applicable for surgical planing and guidance. It can be used for visualization purposes, i.e. to enhance the reality of the display (e.g. volume rendered head with surface rendered skin looks much more realistic than only volume rendered head), and as a possible feature for automatic registration between the patient and dataset coordinate systems (see [2]).

References

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