MR intensity standardization and fuzzy segmentation of MR images

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Short description: We developed an image processing method for MRI intensity standardization. We also introduced new, fast implementations of the fuzzy connectedness algorithm that allows segmentation at interactive speeds. We developed a new segmentation "workshop" for brain MRI segmentation using standardized MR images and the fast fuzzy connectedness algorithms.

Description:

Standardization of the MRI Intensity Scale

A major difficulty with the MRI techniques for most protocols has been that image intensities do not have a fixed meaning, even within the same protocol, for the same body region, for images obtained on the same scanner, for the same patient.

We have developed an image processing method for MRI intensity standardization wherein all images (independent of patients and the specific brand of the MR scanner used) can be transformed in such a way that for the same protocol and body region, in the transformed images similar intensities will have similar tissue meaning. The consistency of the brightness level and contrast of images is considerably improved and scanner dependent intra- and inter-patient intensity variations are substantially reduced after standardization. The transformed images permit predetermined display window settings just like in CT and also facilitate image segmentation.
Figure 1: Histograms for 10 different FSE PD studies. Original histograms (left), histograms after intensity standardization (right).
Figure 2: Images displayed at fixed gray level windows. Original images (first row), images after intensity standardization (second row). In each row, a slice from the PD studies of three MS patients is displayed.

Fuzzy Image Segmentation

Image segmentation techniques using fuzzy connectedness principles have been used successfully in several large applications in recent years: MR brain image analysis for quantifying white matter lesions and brain tumors, segmentation of vessel structures and artery-vein separation in MRA, craniofacial muscle segmentation, and mammographic fibroglandular density quantification. However, there were several parts in these techniques where improvements can be achieved.

When the fuzzy connectedness algorithms were first introduced they could not be used for interactive processing due to their excessive computational requirements. In an attempt to substantially speed up the fuzzy connectedness methods we studied systematically a host of 18 'optimal' graph search algorithms. We demonstrated, by extensively testing these algorithms on a variety of 3D medical images taken from large on-going applications, that substantial improvement in speedig up the fuzzy connectedness methods is achievable with a combination of well-chosen algorithms and modern hardware.

We showed that utilizing efficient algorithms and careful selection of implementations can speed up the computation of fuzzy connectedness values by a factor of 16 to 29 (on the same hardware), as compared to the implementation previously used in applications utilizing fuzzy object segmentation.

Using the fast algorithms on fast hardware, interactive speed of fuzzy object segmentation is achievable. This leads to a new line of segmentation techniques. If images having intensities with tissue-specific meaning (such as standardized MR images) are utilized, most of the parameters for the segmentation method can be fixed once for all, all intermediate data can be computed before the user interaction is needed and the user can be provided with more information at the time of interaction. The reliable recognition (assisted by human operators) and the accurate, efficient, and sophisticated delineation (automatically performed by the computer) can be effectively incorporated into a single interactive process.

An MRI Protocol-independent Brain Segmentation Method

We devised a segmentation "workshop" for brain MRI segmentation wherein a protocol-specific segmentation method can be quickly fabricated. The method combines the robust, accurate, and efficient techniques of fuzzy connectedness segmentation with standardized MRI intensities and fast...
algorithms. The result is a general segmentation framework that efficiently utilizes the user input (for recognition) and the power of computer (for delineation). This same two-phase method has been applied to segment brain tissues from a variety of MRI protocols.

**Figure 3:** Slices from a standardized FSE PD, T2 study pair (left images of rows 1 and 2), the corresponding slices from the scenes depicting the fuzzy affinity relations for the GM, WM, and CSF objects (first row), the same slices from the scenes depicting the connectedness values (second row), and the hard (binary) segmented objects (third row). Binary mask for brain parenchyma is shown in the bottom left image.

**Publications:**
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- Fuzzy-connected 3D image segmentation at interactive speeds [8], **Nyúl, László Gábor** [4], **Falcao Alexandre X.** [9], and **Udupa Jayaram K.** [5], GRAPHICAL MODELS, 2002///, Volume 64, Issue 5, p.259 - 281, (2002)
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