Algorithms for automatic calculation of quality control metrics for ACR accrediatation compliance

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Introduction: In order to maintain certification of MR scanners accredited by the American College of Radiology (ACR), a weekly quality control (QC) program must be established for each system. This entails scanning of an ACR designed phantom followed by quantitative assessment of four image quality metrics that include geometric accuracy, high and low contrast resolution, and artifacts (signal-to-noise ratio (SNR) and ghosting). While these tests can be performed manually by a trained reviewer, this process is time consuming, particularly for multiple MR scanners and is prone to human error. Calculation of these metrics is not only ideally suited for computer image processing but also necessary if this potentially labor intensive process is to be minimized through automation.

The aim of this work is to describe the development of a set of image processing algorithms to calculate the four image quality metrics required by the ACR as part of an automated ACR compliant MR QC program.

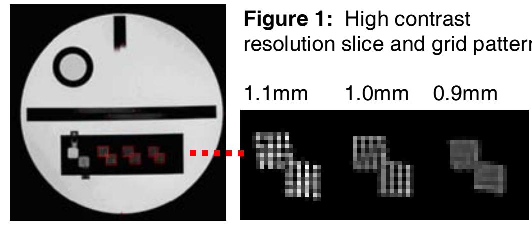

Figure 1: High contrast resolution slice and grid pattern.

Methods: We have developed a web based, automated QC program in accordance with ACR maintenance of certification guidelines. Briefly, an ACR QC phantom is scanned using the ACR recommended imaging protocol (sagittal localizer and axial data set). Images are then DICOM pushed to a dedicated server that first detects these data and then calculates the four QC metrics. These metrics are calculated by application of the following four algorithms:

High Contrast Resolution as defined by the ability to distinguish the high contrast grid pattern of slice one of the axial data set (figure 1) is calculated by first classifying each pixel within the pattern according to the horizontal fuzzy logic classification scheme in figure 2. After classification, seven horizontal patterns (figure 3) are used to grade each row. A row is determined to be resolved if one of two fuzzy logic conditions are met. These are: 1) a row pattern has a grade of "good" and the four pixels of interest have grades of "possible" or higher. 2) A row pattern has a grade of "possible" and the four pixels of interest have grades of "very good". The process is then repeated for the vertical direction at that resolution level and the entire process is then repeated for the next resolution grid.

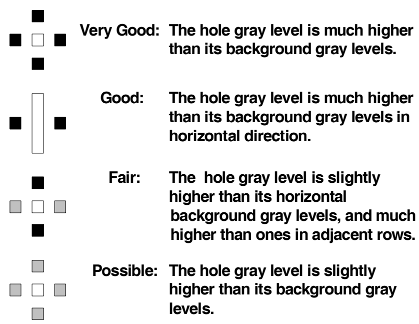

Figure 2: Fuzzy logic classification categories for horizontal high contrast resolution

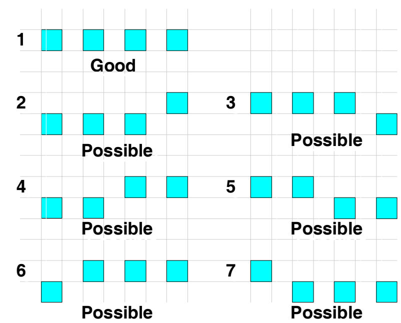

Figure 3: Fuzzy logic grades for classified horizontal hole patterns.

Low Contrast Resolution is defined as the ability to distinguish a spoke pattern of disks from their background (Figure 4, axial data slice 11). This is a multi-step process with the first being the determination of the center of the low contrast area (enlarged region, Figure 4). Next, potential disk locations along each spoke are identified by applying simple thresholding of the central region along with the calculated central point and prior knowledge of parameters including the spoke angles, radial distance to each disk, and disk radius. All potential disk locations are found by applying dynamic thresholding to each potential disk region. A disk template is then placed on each of these points and pixels that fall within the template disk area are tested against the distribution of the template's background area. A point is considered as a possible disk center if 50% of the points within the template's disk are above the background threshold. Every point that passes is then scored by applying four metrics (radial distance to center, average gray level within the template disk, distance between calculated and expected location, and # pixels in the template disk above a threshold value). The pixel with the highest score is selected for each disk in a spoke. The spoke is marked as found if the angle difference of the three disks is within a predefined tolerance. If the current spoke is determined to be resolved then the next spoke is processed similarly until a failure state is reached (less than three disks per spoke or the angle difference is greater than tolerance).

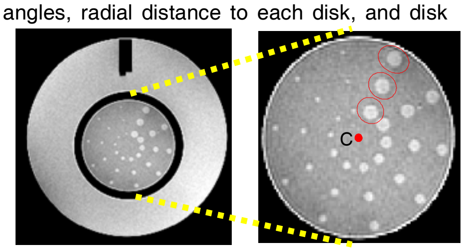

Figure 4: Low contrast resolution pattern and their potential disk regions

Distortion is measured by first calculating the length of the phantom on the sagittal localizer image. Axial images are then processed to calculate horizontal and vertical diameters of the phantom in cross section. Distances are measured between apposing phantom edges. Edges are determined by first applying a 3x3 Sobel mask to the image and then finding the largest pixel value after Sobel filtering (inflection point of edge gradient).

SNR, percent image uniformity, and percent signal ghosting are calculated by according to the method described in the ACR MRI QC manual [1].

Results: High and low contrast resolution, distortion, and SNR have been calculated on 7,709 ACR phantom data sets from 19 MR systems (two Siemens (Erlangen, Germany) Espree and one Avanto 1.5T scanners, 14 GE Healthcare (Waukesha, WI) 1.5T systems and two GE Healthcare 3.0T MR scanners) using these algorithms as part of our web based automated QC program. To further validate these tests, 243 exams were compared to manually calculated values for all four metrics from a single observer. For high contrast resolution, the automated algorithm detected a higher spatial resolution in 3% of cases. For low contrast resolution, the difference between the number of spokes identified by the automated algorithm and the observer was less than or equal to 1 in 98.5% of cases. The difference between the observer and computer measured distortion was < 0.7mm. Signal to noise ratio, percent image uniformity, and percent signal ghosting were equal.

Discussion: Using image processing techniques coupled with fuzzy logic and statistical analysis, it is possible to accurately calculate those parameters required to be measured as part of a weekly QC program in accordance with ACR accreditation guidelines. Further, these algorithms can be integrated into an automated processing tool, thereby reducing human effort and streamlining the ACR QC process.

References:

1. Magnetic Resonance Imaging Quality Control Manual, American College of Radiology, 2004
2. A First Course in Fuzzy Logic, Third Edition, Hung T. Nguyen & Elbert A. Walker, Chapman & Hall/CRC, 2005