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Development of NEMA-based Software for Gamma Camera Quality Control

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We have developed a cross-platform software application that implements all of the basic standardized nuclear medicine scintillation camera quality control analyses, thus serving as an independent complement to camera manufacturers' software. Our application allows direct comparison of data and statistics from different cameras through its ability to uniformly analyze a range of file types. The program has been tested using multiple gamma cameras, and its results agree with comparable analysis by the manufacturers' software.

KEY WORDS: Nuclear medicine, quality control, single-photon emission computed tomography (SPECT), performance measurement, image quality analysis

INTRODUCTION

The flawless performance of nuclear medicine cameras is of paramount importance for the accuracy of clinical diagnostic studies because any malfunction may create image artifacts and alter patient diagnoses. Therefore, special series of quality control (QC) tests have been designed to ensure optimal camera performance. Depending on the objectives, the extent and scope of these tests varies. After camera installation, the broadest and most complete QC assessments or "acceptance tests" are done to ensure the correct performance of the system, verify its compliance with the published (or manufacturers') specifications, and establish the benchmark conditions for all future measurements. Later, over a camera's entire period of clinical operation, hospital technicians and/or physicists regularly perform various QC tests—some daily, others weekly, monthly, or yearly. The purpose of these tests is to monitor day-to-day camera performance and detect

changes from the baseline values. Additionally, QC tests may be performed to compare characteristics of different systems and to optimize the quality of clinical studies.

To standardize these tests, the National Electrical Manufacturers Association (NEMA) regularly compiles documents that describe how to perform, analyze, and report QC tests for scintillation cameras. The latest of the NEMA standards for single-photon emission computed tomography cameras is NU-1 2001.¹

The results of tests performed according to NEMA recommendations allow for easy monitoring and reporting of camera performance, comparison of different systems, and/or creation of consistent QC protocols. However, the fair comparison of different systems requires not only standardized acquisition practices but also that analysis be done with standardized data processing software. The lack of such software poses a major challenge in the clinical environment as, in the majority of cases, the QC analysis is done using programs supplied by the camera manufacturer, many times without a guarantee of NEMA

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compliance. Additionally, manufacturer-provided QC software is usually camera-specific; this means that often data from two different cameras cannot be analyzed by the same program, even if both cameras were built by the same manufacturer.

To circumvent this problem, we have developed a software application that implements the basic scintillation camera QC analyses, as described in the most recent NEMA standard. Our software, named Nuclear-Medicine-QC (NMQC), allows multiple types of QC test data to be analyzed within a single application and enables the comparison of different cameras in a uniform way. Thus, our application complements camera-specific manufacturers' software by providing an independent analysis platform for cameras of diverse types and makers. Both planar and tomographic QC tests are implemented, allowing examination of camera performance in a number of important areas.

DESIGN CONSIDERATIONS

User Perspective

As outlined by Hines et al.² and Groch and Erwin,³ there are several issues related to QC testing that need to be taken into account when designing data analysis software. The most important are the following:

1. Due to the high frequency of the tests, the analysis needs to be simple and fast, recording the most relevant numerical results for further analysis.
2. Software used to display the data must allow for detailed visual inspection of the acquired images. This should include flexibility in how data values are mapped to screen colors for visualization (ie, different colormaps, intensity scales, and intensity ranges should be available), as well as the ability to zoom and pan across the data.
3. The main objective of routine QC tests is to detect changes from the baseline conditions. To this end, graphs and/or tables reporting results and evaluating changes in camera performance over time should be included in the analysis software.
4. Routine QC programs should take into account the fact that requirements for tomographic

performance of the camera are usually more stringent than those for planar imaging; therefore, both types of tests should be performed and analyzed.

5. The analysis of the measured data needs to be sensitive to the important changes in camera performance, but also allow for proper identification of the effects that are insignificant and will not be detrimental to the clinical studies.
6. During the analysis process it may be necessary to retrieve some of the acquisition details, check camera parameters, or verify the identity of the file. As this information is encoded in the file header, the analysis software should read it, properly identify and use the information required in the analysis, and allow the user to display the header if needed for other purposes.

Technical Perspective

Software engineering involves making tradeoffs between conflicting goals. In developing the NMQC application, we had to balance technical constraints and desired functionality while working within availability limits on time, money, and development staff.

In our case the selection of the platform used to code the application was based on the following considerations: The fundamental functional requirement of the software was that it implement NEMA quality control processing of digital imaging and communication in medicine (DICOM)⁴ format gamma camera data. A desirable nonfunctional requirement was cross-platform compatibility: the ability of the software to run on diverse hardware and under multiple operating systems.

We primarily considered three options for the programming language in which to write the NMQC software, all of which satisfy the cross-platform requirement: C++,⁵ Java,⁶ and MATLAB from The Mathworks. Each language has its strengths and weaknesses, as well as its promoters and detractors. Among the advantages of C++ are its speed and maturity, as well as the broad availability of useful libraries. Java is more uniform across platforms than some C++ toolkits, is also quite mature, and has many image-processing capabilities. Our eventual choice, MATLAB, offers programming simplicity, has

excellent image-processing and plotting capacities, and features built-in DICOM support. Also, the speed of development afforded by MATLAB's built-in functionality made its use advantageous. For example, the integrated plotting functionality that exists in MATLAB would require additional external libraries and substantially more programming to implement in C++.

Another attractive feature of MATLAB is the Graphical User Interface (GUI) Design Environment.⁷ This drag-and-drop user interface design tool allowed quick prototyping of the application's user interface. While this capability is not unique to MATLAB, it provides a good complement to the quick development cycle typical of MATLAB algorithmic code.

For all its development advantages, MATLAB would not be a desirable platform if users were required to own a copy of MATLAB to execute our program. This was the primary concern with choosing a software platform created by a private company rather than an industry standard such as C++. However, by installing the free MATLAB Common Runtime (MCR), anyone can run our software, even if they do not own a license for MATLAB or the Image Processing Toolbox. Alternatively, the program can be run directly from within MATLAB by users who do have a copy installed. In our opinion, MATLAB is used and accepted in both industry and academia to a degree which gives us confidence that, despite being a private company's offering, it is a safe choice in terms of both longevity and cross-platform support.

METHODS

General—File Formats and Display

Our NMQC software reads image and header information from DICOM files, which have become a generally recognized format for medical imaging files. Alternatively, for backwards compatibility and historical comparisons, our program also supports the Interfile⁸ format, which is still used in older nuclear medicine cameras. As mentioned in the “[User Perspective](#)” section, our software displays and uses in the analysis some of the information included in the file header. In particular, the pixel calibration values that are necessary for determination of the spatial resolu-

tion of the camera are obtained from the header. The user, however, can check and override this information, if appropriate. In our clinical experience, this is an important feature for ensuring accurate analyses, especially if incorrect header information has been saved onto read-only media such as CD-ROM. Similarly, based on the header information, the software automatically decides if the data contains a single image or corresponds to a multislice tomographic data set.

NEMA QC Tests

The basic design principle of NMQC was to closely follow NEMA recommendations regarding processing and analysis of the data.

Uniformity Measurement

Planar uniformity measurement is the most important QC test. It is performed daily and is designed to verify camera spatial uniformity and measure deviations from perfectly uniform count distributions.

Both intrinsic (acquired without a collimator and using a point source) and system (with collimator measured with a flood source) uniformities are analyzed using the same method. According to NEMA, the acquired data should be collapsed into a matrix with pixel size equal to 6.4 ± 1.9 mm and filtered with a smoothing filter. The values of integral or differential uniformities, defined as

$$\text{Uniformity}(\%) = \left(\frac{\text{Max} - \text{Min}}{\text{Max} + \text{Min}} \right) \times 100\% \quad (1)$$

are calculated over the whole area of the camera or over five consecutive pixels, respectively. Max and Min are the maximum and minimum pixel counts, respectively. Both calculations are done for the full useful field of view (UFOV) of the camera and the central field of view (CFOV) corresponding to the middle 75% of the UFOV.

For every matrix size that may be used in data acquisition, our software automatically finds the appropriate compression factor, smoothes the data and performs calculation for the largest detector area unaffected by filter boundary effects.

Resolution/Linearity Measurement

The measurement of camera intrinsic resolution and linearity are performed simultaneously using a dedicated lead mask with 1-mm slits spaced every 30 mm in the X or Y direction. The analysis of intrinsic resolution involves calculation of the full width at half maximum (FWHM) and the full width at tenth maximum (FWTM) for each of a series of profiles drawn across the slit lines. The mean, maximum, and minimum values for the set of profiles are then determined. Linearity assessment requires calculation of the deviation of the maximum value of the profile across each line and over the whole surface of the camera.

Profile Analysis

Evaluation of the camera spatial resolution in planar and tomographic modes requires determination of the FWHM and FWTM of a profile drawn across the image of a point or line source (capillary tube filled with activity). The same type of analysis is applied to a single planar image or to a series of reconstructed tomographic slices. For tomographic images, the user has an option to run through the complete data set of reconstructed images to select a single slice image for analysis or to sum several slices and perform the analysis on a multislice image.

Additionally, the distance between two peaks can be calculated and displayed, again in pixels and millimeters. This last test is necessary for verification and/or determination of the pixel calibration values.

Center of Rotation Evaluation

Mathematical formalism of tomographic image reconstruction assumes consistency of the projections. Therefore, verifying the position of the camera's center of rotation (COR) is crucial to the quality of the reconstructed images. The same rule applies and the same test is performed for single- and multidetector systems where tomographic data of a point source (or sources) is acquired over a full 360° rotation of each head. This test must be performed for all collimators and detector configurations that are used in clinical studies. Additionally, for cardiac/general purpose cameras with low-energy high-resolution collimators, the

COR tests include both 90° and 180° detector configurations.

Data analysis includes display of the sinogram (a visualization at a particular axial slice showing transaxial distance on the ordinate and rotation angle on the abscissa) and linogram (a visualization where each successive column is the horizontal sum of the tomographic image at the respective rotation angle) for visual inspection for breaks and discontinuities and calculation of the deviation of the COR value. Figure 5 shows an example of a linogram break caused by misaligned camera detector heads.

Tomographic Uniformity Measurement

Tomographic performance of a camera is usually assessed using a tomographic acquisition of a large cylinder filled with activity. Although a Jaszczak⁹ phantom contains additional elements such as cold or hot spheres and rods, its uniform parts are often used in tomographic uniformity evaluation.

Planar Uniformity Trend Analysis

As mentioned in the “[Uniformity Measurement](#)” section, the most important QC test that is performed daily is the measurement of camera uniformity. Besides allowing for a visual evaluation of image quality, the NMQC software provides the user with quantitative measurements of integral and differential uniformity values for the UFOV and CFOV.

The NMQC Trend Analysis function, described further in the “[Planar Uniformity Trend Analysis](#)” section, was implemented to facilitate the monitoring of camera performance changes over time by providing a graphical plot of aggregated daily planar uniformity test results. Currently, only planar uniformity history is saved, although more extensive historical archiving of test data is planned for future versions.

RESULTS AND DISCUSSION

The following discussion parallels the “[NEMA QC Tests](#)” section and gives the details of our implementation of each of the previously described NEMA QC tests. The figures in this section show examples of our software variously

analyzing output from GE, Siemens, and Philips gamma cameras. NMQC has been tested on numerous gamma camera models, including GE Infinia and Infinia Hawkeye; Sopha-GE DST; Philips Forte, Skylight, and Vertex; and Siemens Ecam, MS2, MS3, Diacam, Orbiter, and Symbia cameras.

General Features

The GUI of our software is organized into two general sections, as shown in Figure 1. First, across the top are general interface controls that

are always visible and apply regardless of the QC test being performed (upper section of Fig. 1). These include menus for loading a file, controls for displaying information about the current file including its header, and controls for the visualization parameters for the current file. Secondly, just below the general controls at the top of the GUI are a series of tabs, each of which corresponds to a different NEMA test. One tab at a time is selected depending on which QC analysis is currently being performed, and the layout of the lower GUI section changes correspondingly (lower portion of Fig. 1). Each QC test tab displays

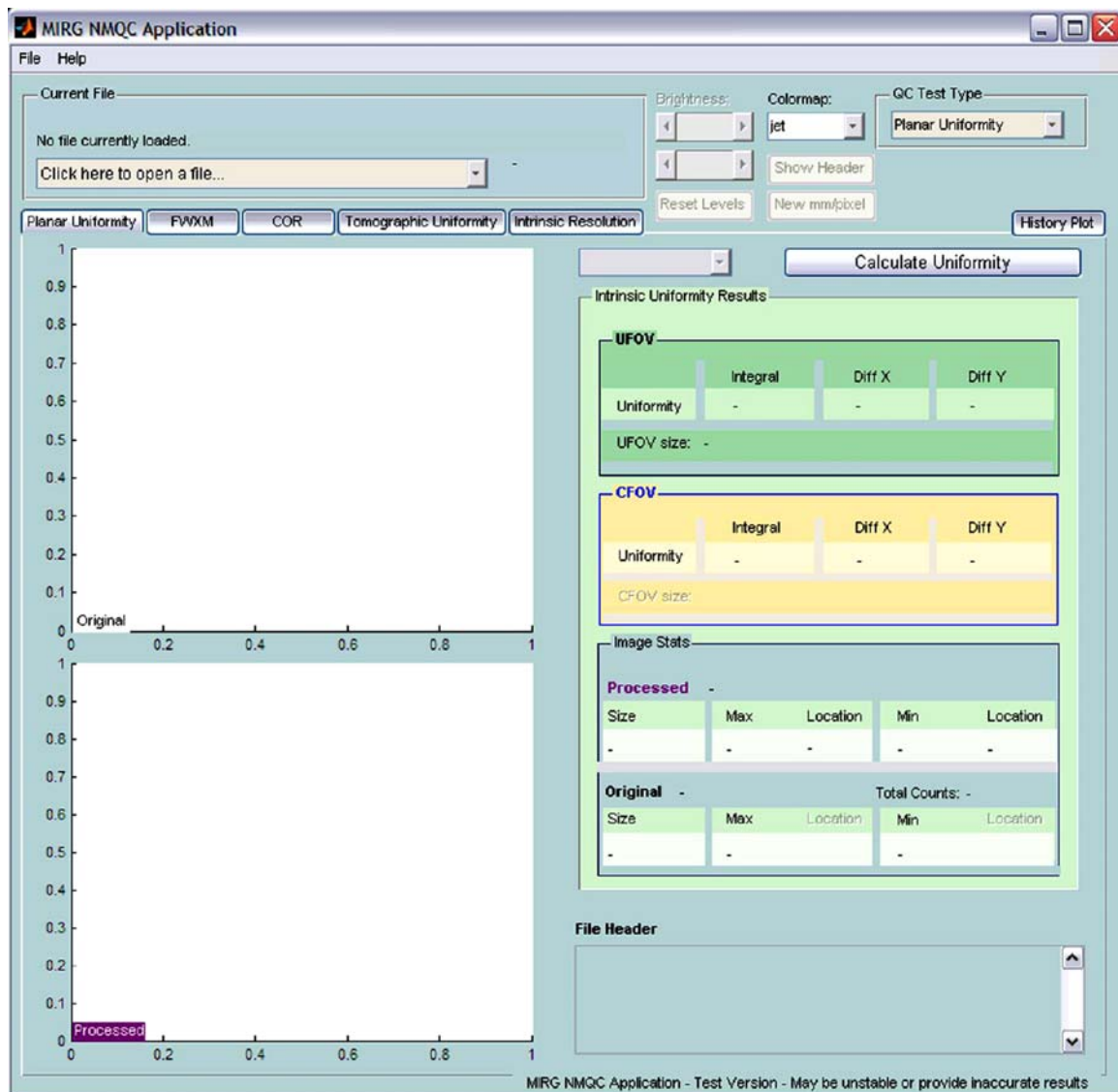


Fig 1. NMQC GUI window.

different data and provides different functionality depending on that particular test's requirements. Because each NEMA test is essentially a stand-alone analysis, organizing the application this way allows the convenience of access to multiple types of QC test processing while at the same time displaying only information and controls applicable to the current method of analysis.

The visualization options that apply to all modes of analysis provide control for how data values are displayed on the screen. There are 16 colormaps provided with adjustable upper- and lower-intensity scale limits, allowing the user to tailor the visualization of individual data files. The general section of the program also provides

options related to the currently loaded file's header, including controls to view, search, and export header information.

Uniformity Measurement

The Planar Uniformity tab GUI displays two different visualizations of the current file, along with statistics obtained from the processing of the file. Figure 2 shows an example of the planar uniformity analysis screen. In this test, a visual verification of the results is important, so there is also the option of double clicking on the images to open a new window to allow zooming for a closer view. The first visualization window on the Planar

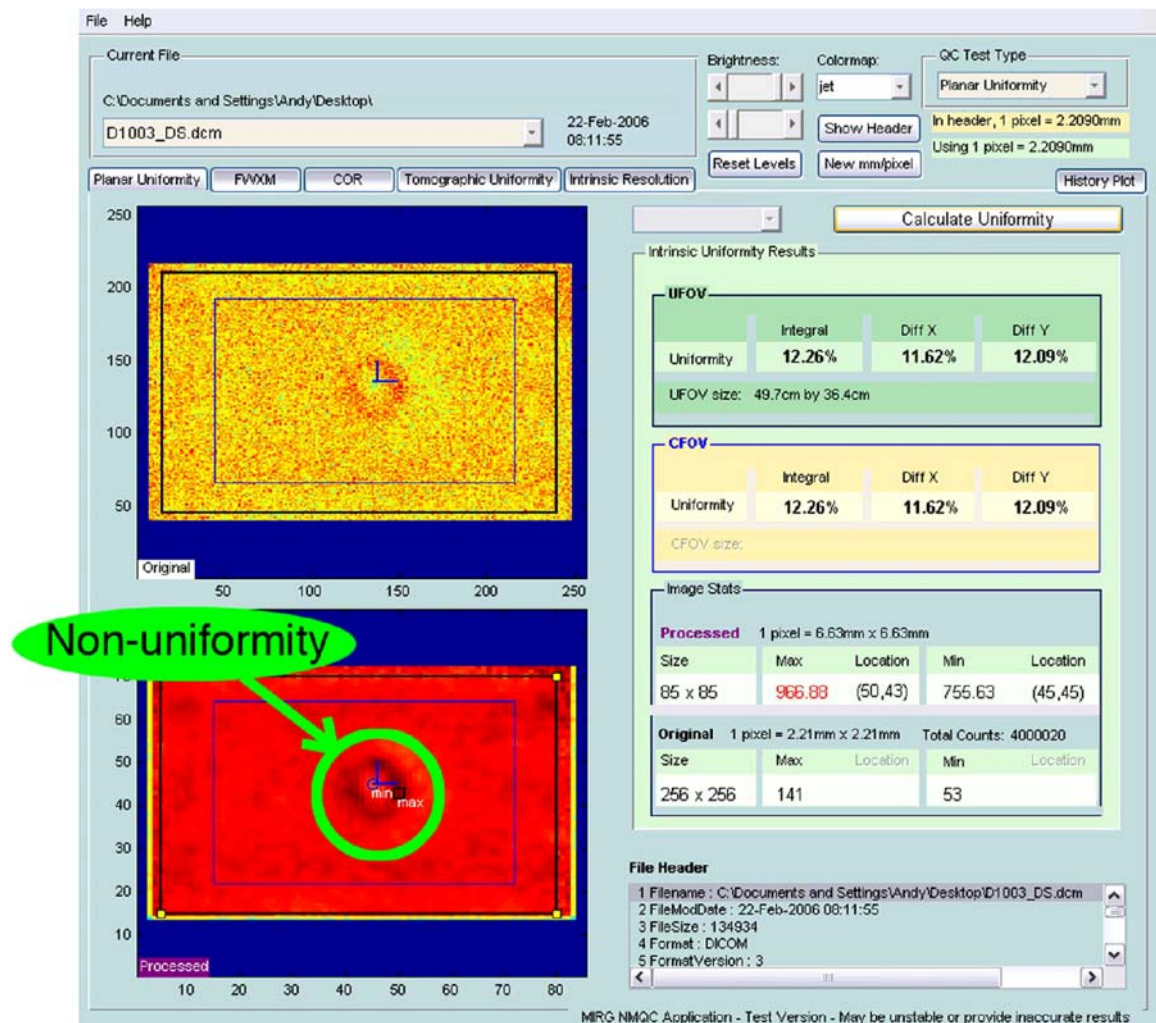


Fig 2. Example of Planar Uniformity screen with a nonuniformity highlighted.

Uniformity tab shows the original, unprocessed file. After processing, the second visualization window on the Planar Uniformity tab shows the image that has been filtered according to NEMA specifications. Also, after analysis, both visualization windows show overlays denoting the UFOV and CFOV, the locations of the maximum and minimum counts, and the locations of the maximum horizontal and vertical count derivatives. Equally importantly, the postanalysis display also provides integral and differential uniformity statistics for both the UFOV and CFOV, along with

image and header information, such as pixel size and total number of counts.

An option to save the results of planar uniformity analysis to a plain-text file is available. The uniformity statistics, processing parameters, and header information are saved in a file with a descriptive name that includes the date, the name of the file analyzed, and the corresponding detector number. This allows archiving of daily QC results in a simple, widely accessible format, and complements the automatic history functionality described in the “Planar Uniformity Trend Analysis” section.

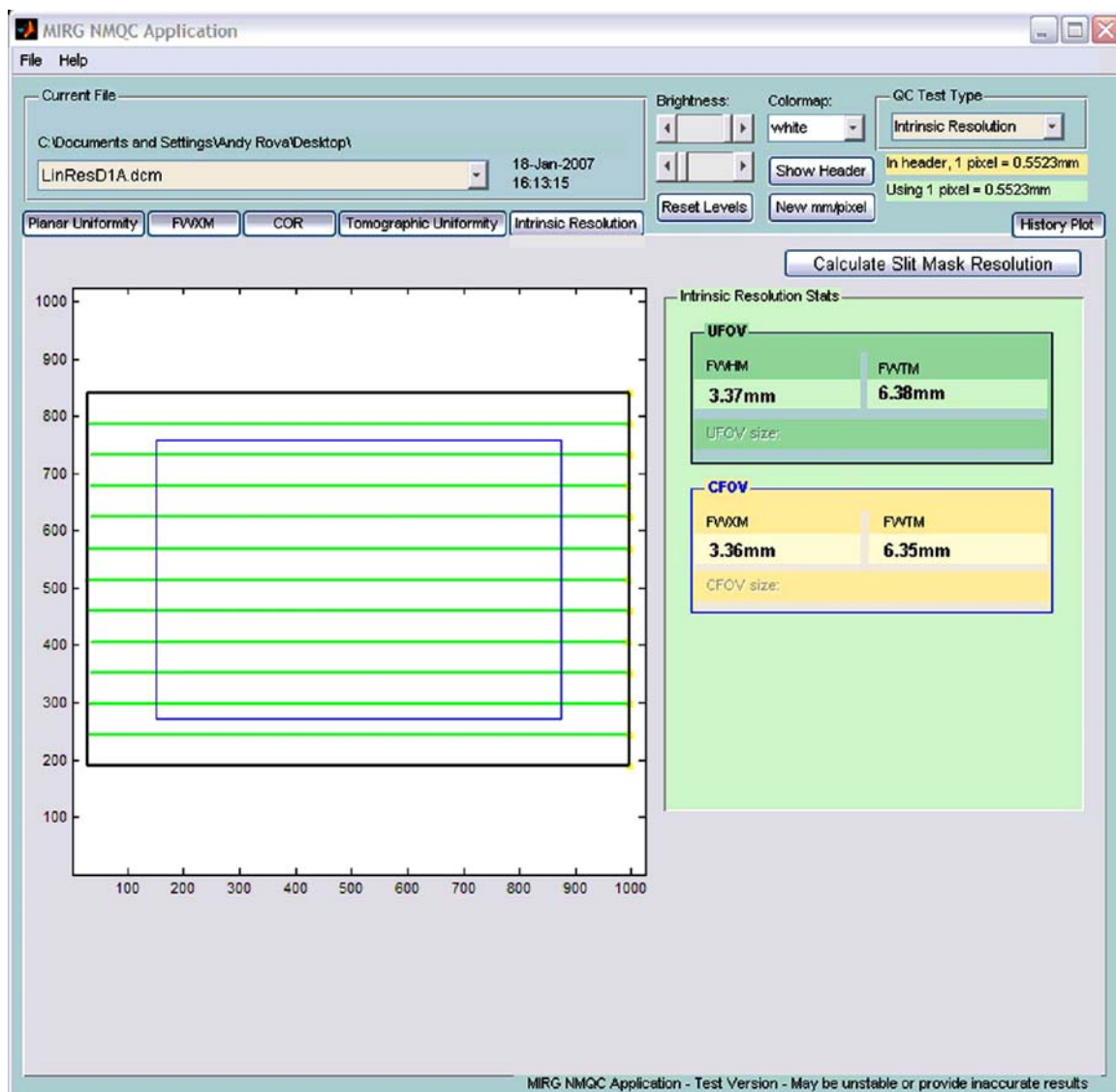


Fig 3. Example of Intrinsic Resolution GUI tab with UFOV and CFOV outlined.

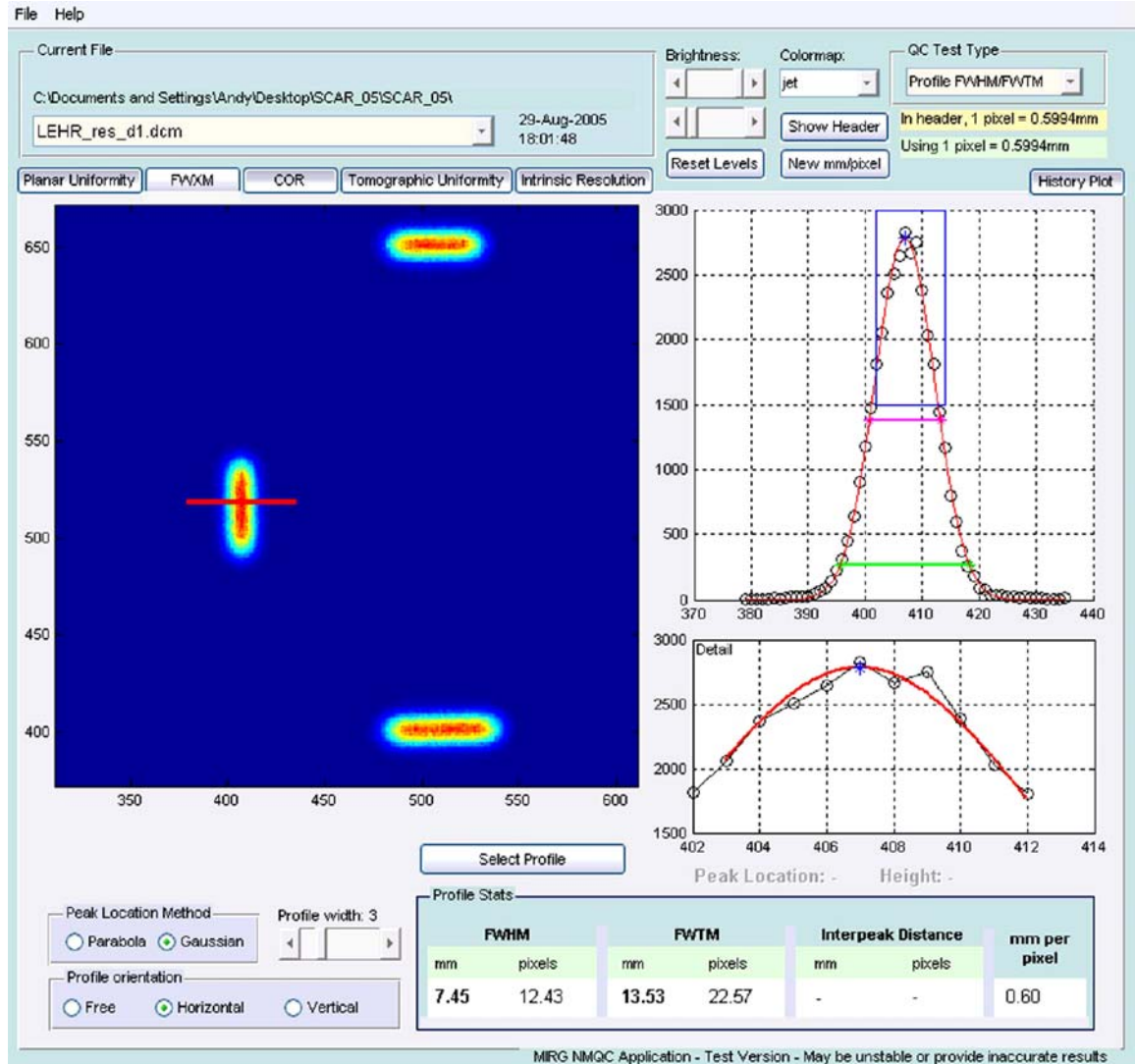


Fig 4. Example of Profile Analysis screen with a profile drawn across a line source.

Resolution/Linearity Measurement

The Intrinsic Resolution GUI tab, shown in Figure 3, allows automated analysis of images captured with an uncollimated detector covered with a special lead mask with slits, as described in the “Resolution/Linearity Measurement” section. The NMQC software automatically searches the image to identify the directions and locations of the lines, determines the boundaries of the UFOV, samples profiles, and performs the aggregated calculations. The numerical results are displayed and the calculated UFOV, CFOV, and detected lines are overlaid on the image for visual verification of the automated processing.

Profile Analysis

The GUI for the Profile Analysis tab, displayed in Figure 4, provides a visualization of the current file along with two profile graph displays and profile statistic information. After opening a file to be analyzed, the user selects the method to be used to locate the peak of the selected profile. Our software provides two options: the NEMA-specified parabola method or a fitted Gaussian method.¹

¹In our experience, using a fitted Gaussian curve provides a useful complement to the NEMA profile measurement method.

At this point the user can also adjust the desired width of the profile to be analyzed and choose whether the orientation of allowable profile selections should be arbitrary, constrained to be horizontal, or constrained to be vertical. Once the desired profile characteristics are selected, the user clicks the Select Profile button and then clicks twice on the visualization image, the first click to specify the profile starting point and the second click to specify the profile's end. Between specification of the profile start and end, the mouse's image coordinates and a dynamic profile line are displayed to assist the user in choosing the desired end point.

Once the start and end points are selected, the profile is processed. The first graph display shows the profile plotted with pixels on the abscissa and counts on the ordinate. In addition, the calculated

peak location, FWHM, and FWTM are displayed. Also, in the case of the Gaussian method, the fitted curve is overlaid on the graph. The second graph display shows a detail of the profile peak, along with the fitted curve and peak location. If a profile spanning two peaks is selected, the interpeak distance (in both millimeters and pixels) will be calculated and displayed instead of FWHM/FWTM statistics. In addition, the Profile Analysis GUI image visualization supports zooming and panning of the current image to facilitate easier selection of specific profiles for measurement.

COR Evaluation

The COR tab GUI provides two image visualizations. The first is of the current image and the second shows either a linogram (Fig. 5) or a

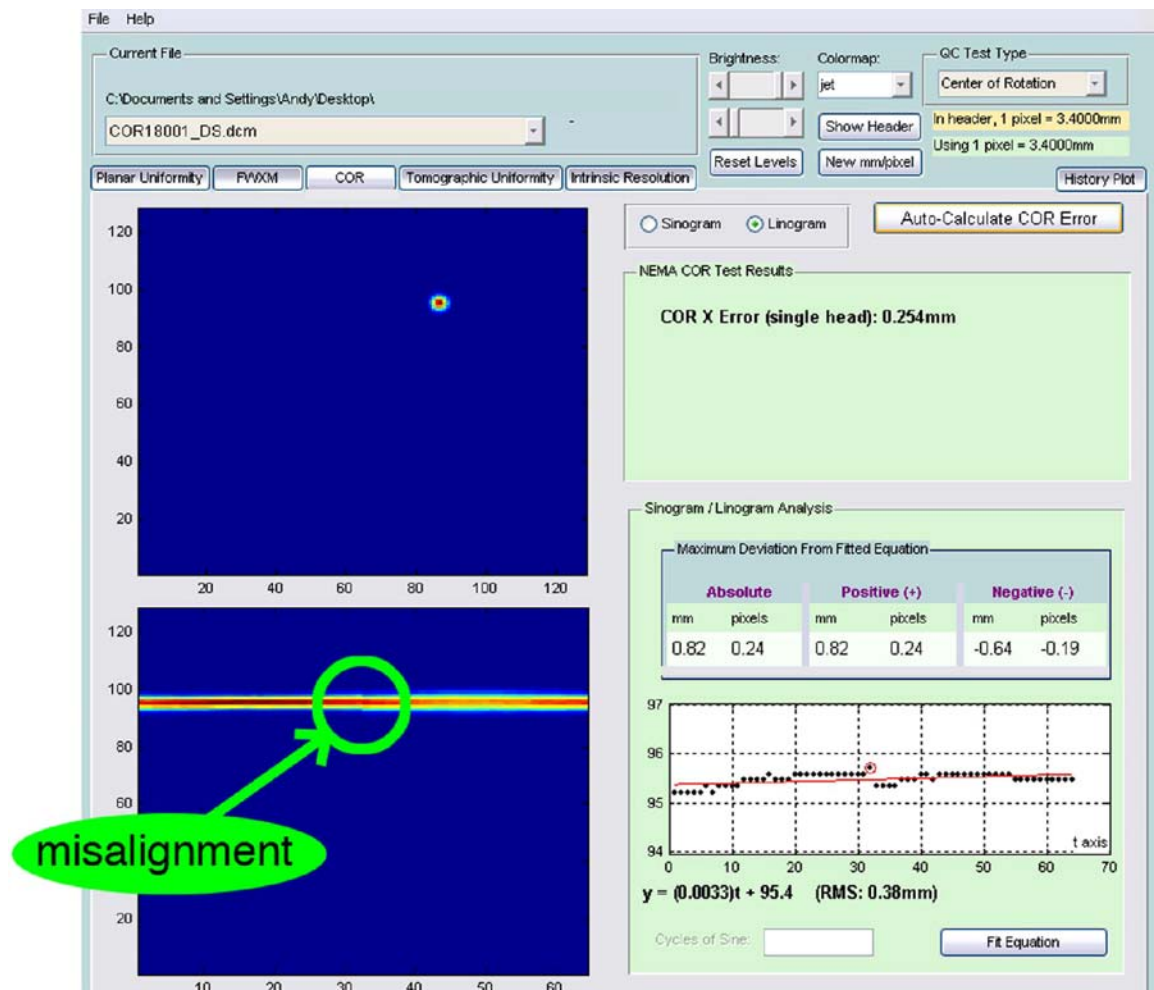


Fig 5. Example of linogram and fitted equation. Note the break in the linogram due to misaligned detector heads.

sinogram (Fig. 6). Additionally, the NMQC software fits a straight line to a linogram and a sinusoid to a sinogram and calculates and displays the parameters of the equation and values of the deviations between the experimental data and these ideal curves. For single point-source data, our application also calculates the error in the X direction according to NEMA specifications.

By clicking and dragging on the current image visualization, the user can choose the horizontal location at which the linogram is calculated, and the linogram display automatically updates to reflect these changes.

Tomographic Uniformity Measurement

The Tomographic Uniformity mode of the NMQC software (Fig. 7) allows the user to select and display the required tomographic slice or to sum the slices and perform the analysis using a multislice image. Next, the user selects the shape of the region of interest (ROI) that will be used in the uniformity calculation. Available ROI types include rectangular, elliptical, and free-drawn shapes. At any time the image may be zoomed in or out and panned to allow for a better visual inspection of its details.

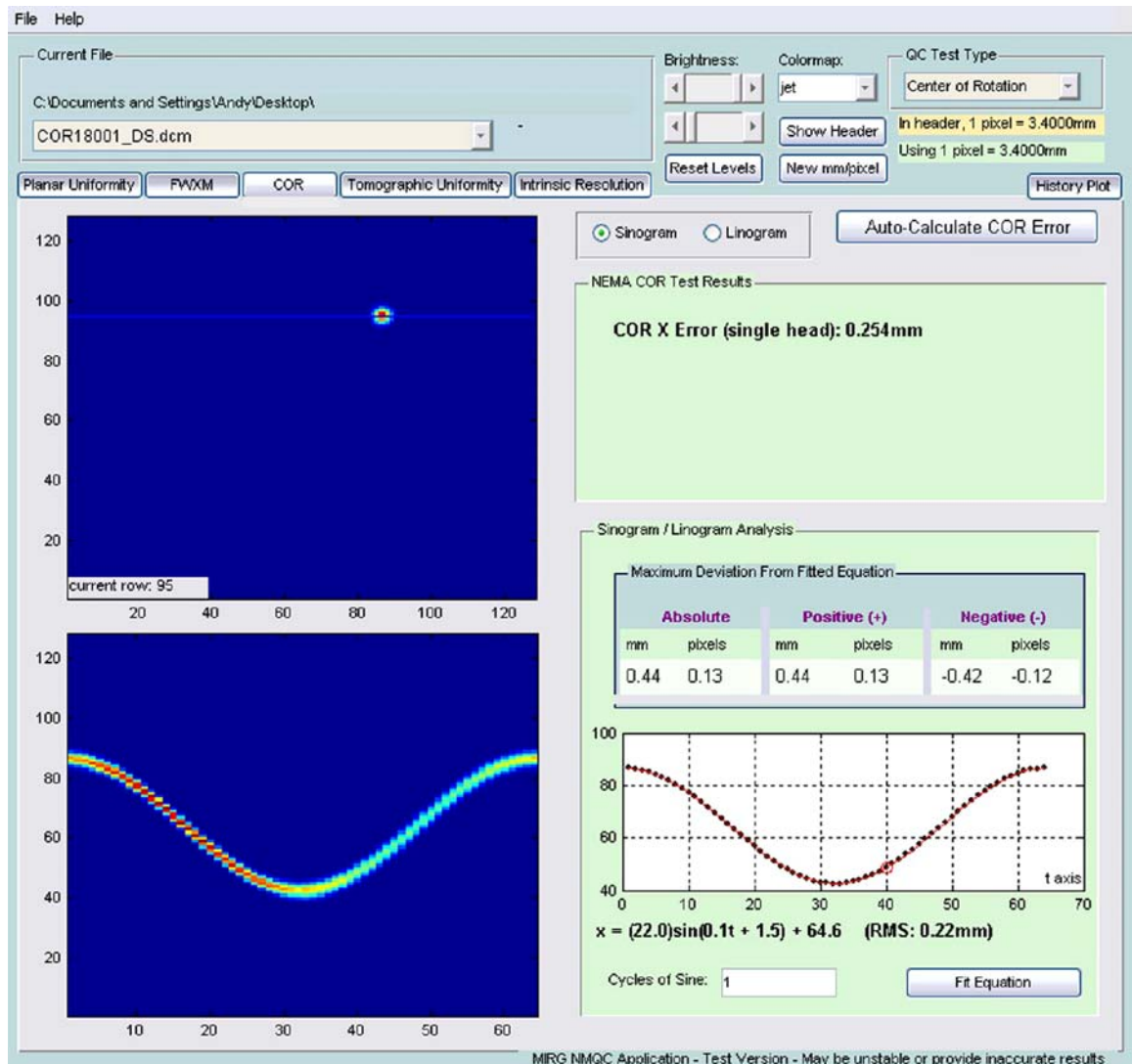


Fig 6. Example of sinogram and fitted equation.

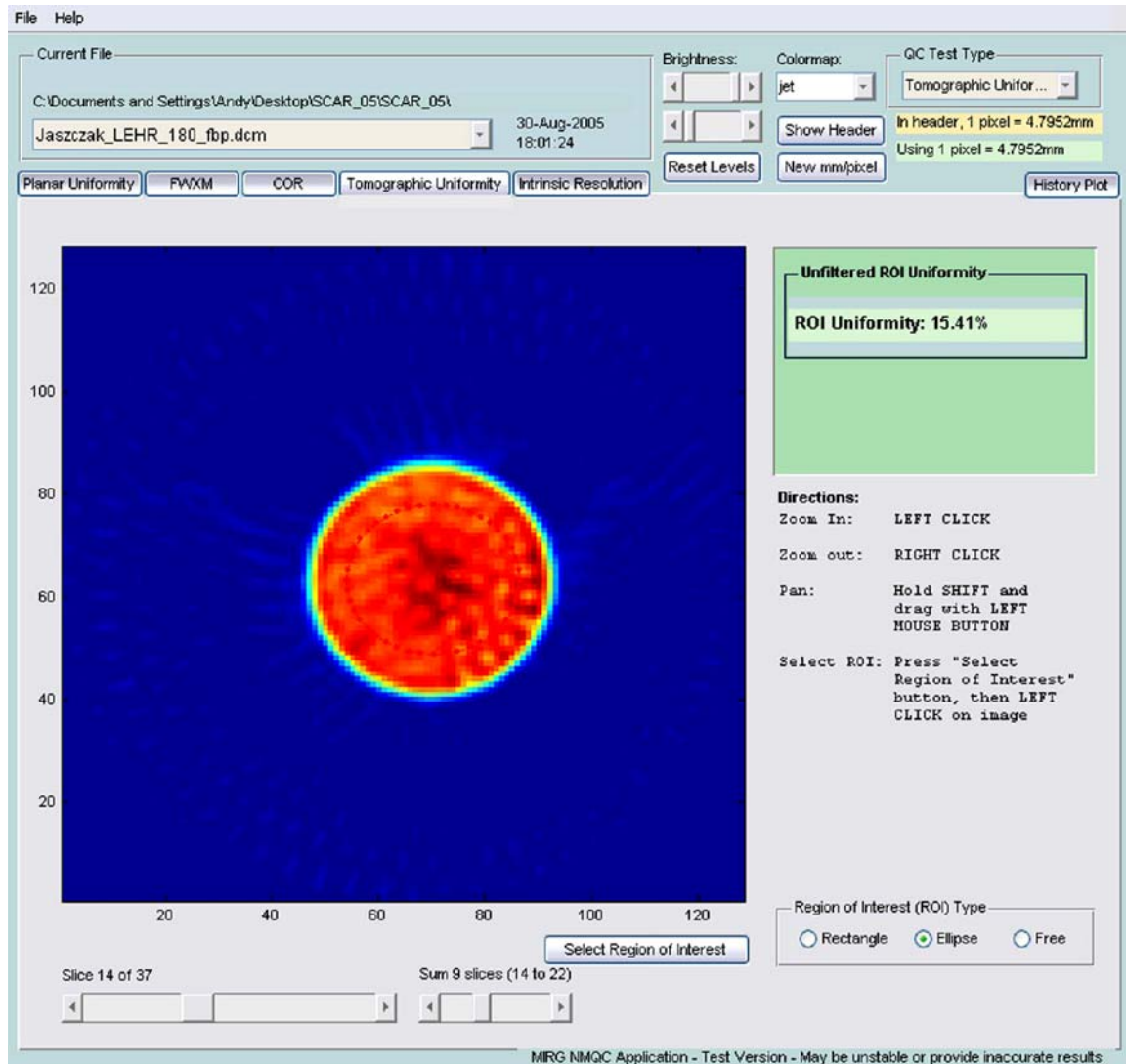


Fig 7. Tomographic Uniformity GUI tab showing summed slices of reconstructed Jaszczak phantom data.

Planar Uniformity Trend Analysis

Because it is important to recognize gradual changes in gamma camera uniformity, our software automatically saves the date and statistics from each planar uniformity analysis that is performed. The History Plot GUI tab, shown in Figure 8, provides two graphs that visualize this information, one for the UFOV and one for the CFOV. For each FOV, the date is along the abscissa and the percentage calculated uniformity is along the ordinate. Each FOV graph also shows separate color-coded plots for integral uniformity, horizontal differential uniformity, and vertical differential uniformity.

The historical planar uniformity data is saved in an easily accessible location as an Extensible Markup Language¹⁰ (XML) file, which is a cross-platform format viewable in many web browsers.

CONCLUSION

We have developed an integrated software suite implementing NEMA tests for nuclear medicine scintillation cameras. Our application is written using the MATLAB environment, which has several benefits, the foremost of which is cross-

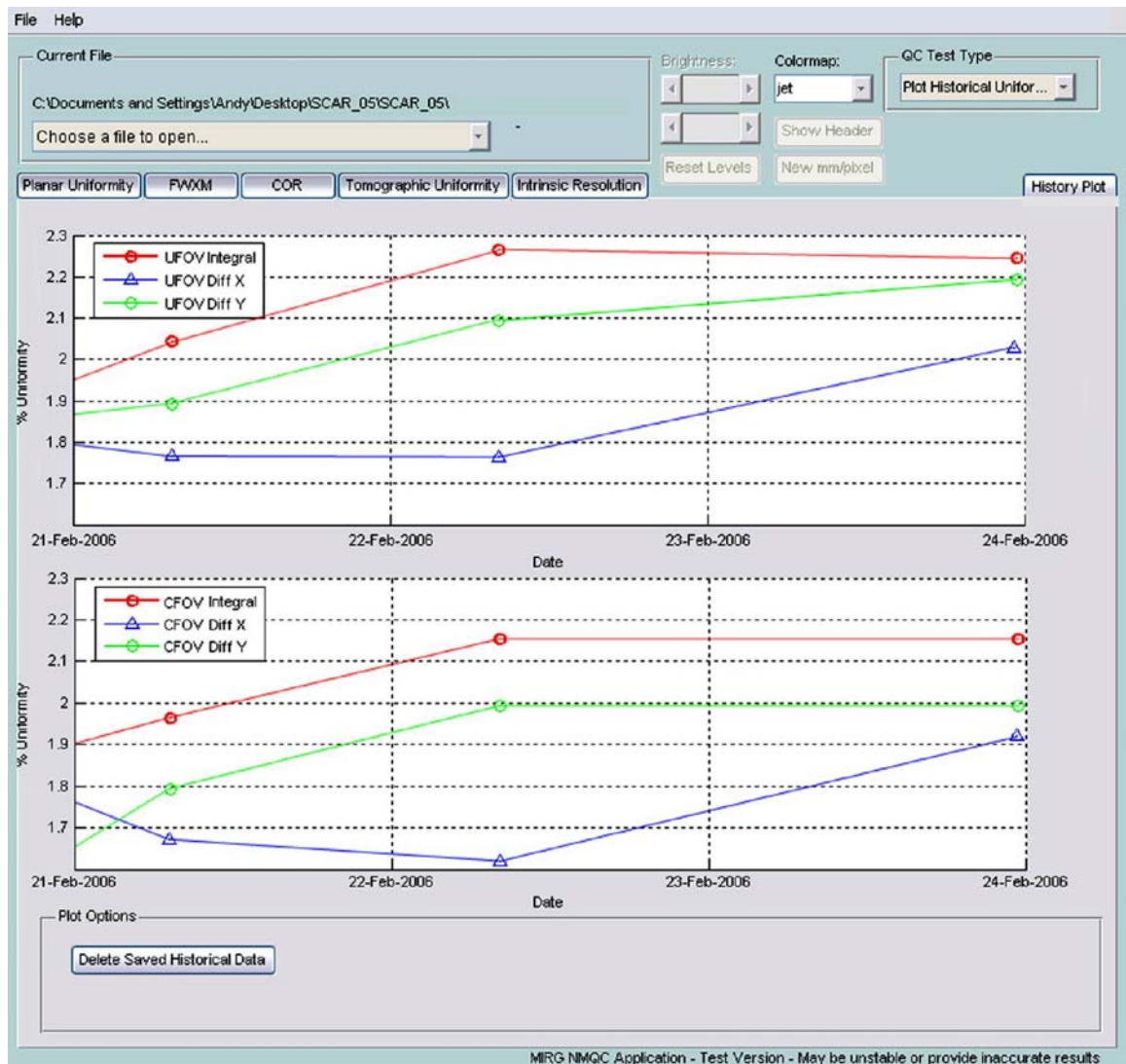


Fig 8. Planar uniformity history graphs.

platform compatibility. Because MATLAB runs on Microsoft Windows, Linux, Apple's Mac OS X, and Sun Solaris, so does our software.

Our application gives a useful overview of a camera's current performance, and provides the ability to track how its uniformity varies over time. An important advantage of our independent, NEMA-based QC software is that data from cameras of different brands can be used as input to our program and analyzed in a consistent way,

allowing a fair comparison of different cameras' performance. Our application is easy to use and provides analysis which is both independent of and complementary to that performed by gamma camera manufacturers' proprietary QC software. Future developments will include the extension of NMCQ to analyze data from coincidence (positron emission tomography) cameras. NMQC is not currently publicly available—more information can be found at <http://mial.fas.sfu.ca/researchProject.php?s=325>.

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