A SEMI-AUTOMATED QUALITY ASSURANCE TOOLBOX FOR DIAGNOSTIC RADIOLOGICAL IMAGING

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Keywords: Automated Quality Assurance, Diagnostic Radiology, Image Processing, Data Management System.

Abstract: Magnetic Resonance (MRI), Computed Tomography (CT) and Ultrasound (US) are three of the most commonly used clinical imaging modalities. The aim of this study was to establish a Quality Assurance program for MRI, CT and US scanners. A well-designed quality assurance program is of utmost importance in the clinical setting, because it indicates whether diagnostic imaging modalities meet the minimum criteria of acceptable performance and because it helps determine those scanner parameters that need adjustment in order to ensure optimum performance. Quality assurance programs that rely on manual data collection and analysis are tedious and time consuming and are often abandoned due to the significant workload required for their implementation. In this paper we describe an integrated software system for automating the process of data collection and management in Quality Assurance for diagnostic radiological imaging. The developed system is comprised of two main units: The Image Processing Unit (IPU) and the Data Management Unit (DMU). The IPU is used for analysing images from different diagnostic modalities in order to extract measurements. The IPU is dynamically linked to the DMU so that measurements are transferred directly to the DMU. This process allows the generation of quality assurance reports for all such modalities.

1 INTRODUCTION

Quality assurance (QA) programs are essential for diagnostic radiological modalities. Apart from their intended purposes to detect changes in the equipment's performance, they allow early identifications of deviations from pre-determined accuracy limits, and reduce unnecessary radiation or radiofrequency exposure to patients. Early on, Task Groups (Och1992) were formed for safety and QA for various diagnostic modalities, both in the USA and Europe. Price et. al. (Price1990) developed basic algorithms and procedures for Magnetic Resonance Imaging (MRI), but Bourel et. al. (Bourel1999) was the first to present automatic quality assessment software. A more elaborate effort was the recent work of McRobbie et. al. (McRobbie2002) that summarized results over a period of 8 years, for 17 MRI scanners, and recommended standards for corrective action.

In this work we take advantage of prior efforts for developing QA programs and protocols for diagnostic radiological equipment using methodology and guidelines proposed by the American College of Radiology (Radiology1996), the American Association of Physicists in Medicine (AAPM) and the Eurospin tests (Lerski1993), to develop algorithms and semi-automated procedures to perform QA in MRI, Computed Tomography (CT), and Ultrasound (US). No prior work has been reported that involves a generalised and comprehensive approach for QA for all these modalities, that uses fast, semi-automated procedures, employing basic and advanced image processing for data analysis and generation of results, as proposed in this work. Such effort is realised by developing an Image Processing Unit (IPU) that provides all the necessary functionalities required for assessing the quality of medical images. The IPU is integrated with a Data Management Unit

Constantinou C., Grondoudis A., Christoforou A., Constantinides C. and Lanitis A. (2006).
A SEMI-AUTOMATED QUALITY ASSURANCE TOOLBOX FOR DIAGNOSTIC RADIOLOGICAL IMAGING.
In *Proceedings of the Eighth International Conference on Enterprise Information Systems - AIDSS*, pages 216-221
DOI: 10.5220/0002445802160221

(DMU) in order to allow data transfer and provide a data repository for longitudinal serial measurements and results from diagnostic equipment.

The main focus and value of this work relates to the development of an integrated software system that deals effectively with the application of systematic quality control and quality assurance control programs for diagnostic radiological imaging equipment. The development of such a system will contribute towards the enforcement of systematic quality control in diagnostic centres in order to ensure optimum performance of imaging equipment.

The QA methodology adopted in our work involves phantom tests and measurements on an MRI, a CT, and an ultrasound scanner. A typical phantom used for MRI quality control is shown in figure1. The general procedure of the QA process is as follows:

a. The parameters of the scanner unit are determined. Recorded parameters include demographic details and data acquisition parameters.
b. Once the scanner is in operation a number of measurements using electronic instruments are performed. In the case of MRI scanners for example, the intensity and uniformity of the magnetic field is measured.
c. Images of dedicated phantoms are generated.
d. Measurements related to the appearance of phantoms in the images obtained in step (c) are extracted. This process usually involves manual inspection of the images and/or the use of image-processing packages.
e. All parameters derived from the previous steps are used to calculate various quantities required for assessing the diagnostic quality of the images. Such quantities assess discrepancies between the expected and actual features.
f. Based on the results obtained from step (e), a QA report is generated.

Significant workload is required for carrying out the method outlined above which justifies our effort for automating this process. Considering that effective quality control procedures involve periodic inspection for each scanner unit, automation of the QA process becomes an essential and integral part of a QA program. With this work, we aim to automate processes in steps d, e and f, and to provide an effective system for managing the application of periodic QA control to a large number of MRI, CT and US scanners.

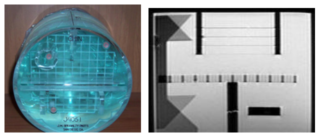


Figure 1: ACR phantom used for MRI QA (left), and a typical sagital MRI image (right).

2 SYSTEM DESCRIPTION

The system is divided into two main components – the Data Management Unit (DMU) and the Image Processing Unit (IPU). The IPU is used to allow the user to perform QA related measurements on medical images. Such measurements can then be transferred to the DMU for further processing and storage.

2.1 Data Management Unit

The data engine of the project is a relational database. It relates clients that own specific imaging units (modalities) with their modalities, and links modalities with periodic QA tests and their results. QA test results are determined based on user-defined parameters and image measurements from analysed images generated from the scanner unit under inspection. The DMU also allows generation of basic reports summarising the QA results based on the information that is stored in the database tables.

The Database Model: The model relates three primary entities as part of the system: the clients, the modalities (that each client owns), and the QA tests that are performed on these modalities. Figure 2 depicts these entities together with their interrelations and some of the secondary tables and entities of the model.

The information stored for every client includes the primary demographic information, such as the owner name and basic contact details. The data collected for each modality is more elaborate. The unit is documented with respect to its name, modality type, client, manufacturer, model, and serial number. Included in the modality are also details on the purchased date and the date the equipment was last-serviced, with related comments. We refer to a test as a collection of smaller, more specific, individual tests that can be run for the unit. These tests (collectively referred to as sub-tests for clarity) focus on specific areas/aspects of the modality under inspection and vary depending on the modality type.

Secondary entities that are part of the database model include users and user types, acceptance criteria, forms of the interface, images and imaging fields, lookups (for standard lookup values) and lookup types, manufacturers, modality types, units and testing tools.

Database Functionality: The database itself and the interface are custom-built software components. Their functionality is unique, defined by the interdependence of the database and the imaging engine. The results from measurements and calculations must conform and comply with required standards but their representation, manipulation and eventual reporting will be unique. The functionalities of database and interface software are outlined in the following:

a. Generation of quality assurance results: Each of the subtests conducted has been programmed to produce a pass/fail result. The outcome of the criterion depends on either one or more (or a combination of) pre-determined factors. These factors include measurements on images, values depending on the imaging unit, standard lookup values, parameters entered by the user etc.
b. *Inter-operability with the imaging engine:* The database's interface can, on demand start the IPU (if it is not already running), and communicate certain sub-tests to be performed by the imaging engine. On returning from completing those tests, the database interface is able to import the resulting measurements and update the relevant tables with the recently acquired/calculated values.

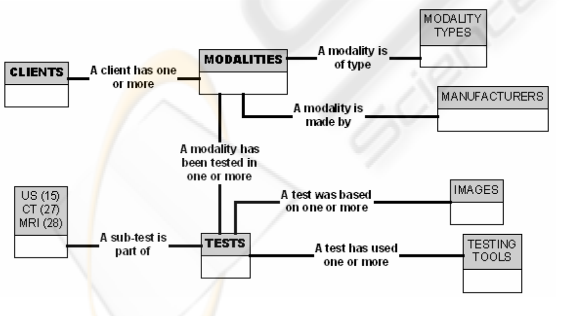
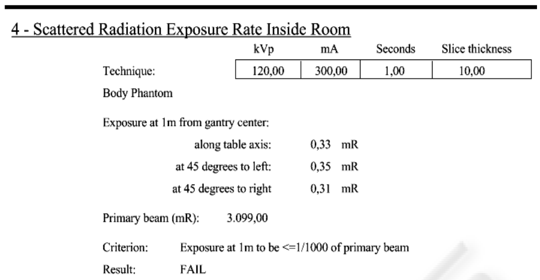


Figure 2: Database Model entities.

c. *Report generation capabilities:* The interface can generate reports that will output the information in the database. There are standard printout reports, for clients, modalities etc., and there are test and sub-test reports that can be customised to include certain parts of a test. An example of a typical excerpt from a report is shown in Figure 3.



4 - Scattered Radiation Exposure Rate Inside Room

	kVp	mA	Seconds	Slice thickness
Technique:	120,00	300,00	1,00	10,00

Body Phantom

Exposure at 1m from gantry center:

along table axis:	0,33	mR
at 45 degrees to left:	0,35	mR
at 45 degrees to right	0,31	mR

Primary beam (mR): 3.099,00

Criterion: Exposure at 1m to be <=1/1000 of primary beam
Result: FAIL

Figure 3: Excerpt from a QA CT report.

d. *Database maintenance and interface customisation*: The database's interface is an integral part of the developed software. All details of most primary and all secondary tables and entities can be edited and manipulated by the users if the system.

e. *Dynamic features of the interface*. The database-interface setup is dynamic. The database or the server can be changed from within the interface with no service disruption. The location of the imaging engine software and the location of the report files are also set dynamically.

2.2 Image Processing Unit

We have developed a dedicated image-processing tool that provides the required functionality for a QA program in diagnostic radiology. In summary, the developed image-processing tool includes the following (region specific or image specific) features:

- Loads and saves images of any format including the DICOM format.
- Allows image data visualisation in different ways (i.e Histogram Viewer, Profile Viewer, 3D viewer, contour plots viewer) and provides tools for windowing and levelling options.
- Includes basic algorithms for image operations, such as thresholding, linear and non-linear filtering, morphological operations, Fourier transformations, histogram equalization and others.
- Includes basic image segmentation techniques such as border extraction methods.
- Allows the user to define regions of interest in an image of any shape or size.

- Performs customised measurements on images, in order to support the determination of the quality of MRI, CT and US images.
- Allows data transfer to and from the DMU, so that the results of the measurements are stored in the database.

The quality of images can be assessed based on dedicated measurements/tests carried out on images of specially designed phantoms. In total, 26 different image tests are supported by the IPU, 13 of which refer to MRI images, eight refer to CT images and the remaining five refer to US images. In all cases the test results are transferred to the DMU, so that appropriate calculations are performed in order to assess compliance with preset standards.

In the following sections we describe typical techniques used as the basis for implementing complete test measurement procedures for each of the 26 tests.

2.2.1 Texture Measurements

In several occasions we wish to obtain measurements that relate to the mean signal intensity, the standard deviation and the signal-to-noise ratio (SNR) in a region of interest (ROI). For this purpose, we have implemented algorithms for obtaining first order texture measurements in an image region. Texture measurements are carried out in a semi-automatic way, since the user is required to specify and/or modify the ROI. Texture measurements are usually used for assessing the homogeneity of image regions, calculating differences in signal strength in image areas corresponding to different materials in phantoms and assessing the contrast between bright and dark tissue regions. Figure 4 shows typical image examples where texture measurements are performed.

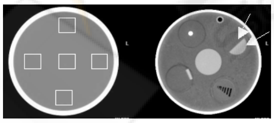


Figure 4: Typical Regions-of-Interest (ROI's) on CT images where texture measurements are performed. (ROI's are indicated by the squares and arrows overlaid on the images).

2.2.2 Locating Points of Reference

On various occasions, phantoms contain objects used as reference points for a number of measurements. Examples of such reference points are shown in Figure 5. To automate the process of analysing test images, the user must be able to locate reference points in images. To achieve this in the developed system we employed either a convolution-based approach or a profile-based approach.

The convolution-based approach is used in noisy datasets (a preferred approach for US images). Based on this approach profiles are extracted in the ROI that contains the points of reference; the extracted profiles are then convolved with a one-dimensional Gaussian function. The resulting vector indicates the positions of the points of reference. Figure 5 shows an example of reflectors in a US image, which are automatically located using the convolution-based approach.

The profile-based approach is used in low noise images. Using this approach the locations of the reference points are determined by detecting the minima loci in the profile data (Figure 6).

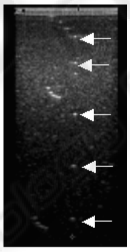


Figure 5: A typical ultrasound (US) phantom image with point-reflector sources, indicated by the arrows.

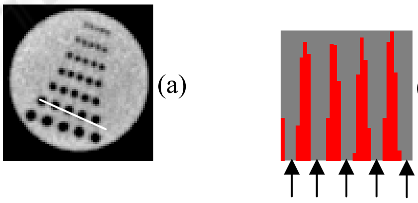


Figure 6: Locating reference points on a CT image of a resolution phantom, using the profile-based method. (a) Axial image of a resolution CT phantom (b) One-dimensional profile from the second row of air holes drilled in an epoxy resin-based insert of the CT phantom; the arrows point to locations of minima.

2.2.3 High Contrast Spatial Resolution

High contrast spatial resolution is the ability of an image device, to produce images where adjacent high contrast objects are distinguishable. In order to assess the ability of imaging equipment to produce acceptable high contrast spatial resolution, a series of high contrast circular objects of varying size and separation is studied. The aim in such cases is to define whether the circular objects are distinguishable at a particular size and separation level. Examples of high contrast circular objects considered for this test are shown in figure 7.

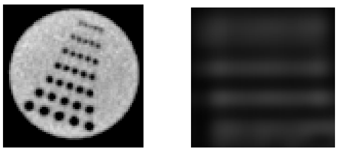


Figure 7: Details of a CT (left) and zoomed MRI image (right) showing the spots used for computing the high contrast spatial resolution. In the case of the MRI image the spots are not distinguishable.

Techniques developed for detecting points of reference in images (see section 2.2.2) were employed in this case, to count the number of objects detected in each region of interest.

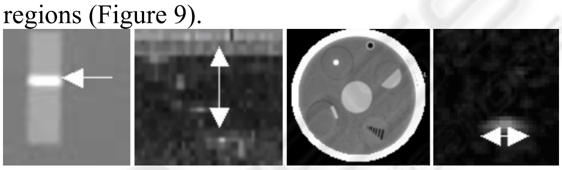
2.2.4 Distance Measurements

In several occasions it is necessary to measure distances between structures and/or the dimensions of image objects. To perform distance measurements, the user defines the ROI containing the structure of interest and the required measurements are performed automatically. Typical cases where distance measurements involved include:

- Measuring the width of image structures. The user draws a profile across the image structure and based on the extracted profile data, the width of the structure is calculated (Figure 8a).
- Measuring the distance between reflectors. Reflectors in an image region are automatically located (see figure 5 and figure 8b) and the distances between them are calculated.
- The calculation of the distances and dimensions of circular structures (see figure 8c). In this case we extract the boundaries of a circle and then establish the attributes of the circle (i.e height, width, center).
- Measuring the width of reflectors in noisy images (see figure 8d). The reflector is first located and then a profile is extracted across the center of the reflector. Gaussian functions of different standard deviations are convolved with the extracted profile – the standard deviation value that produces the best fit is used for estimating the width of the reflector.

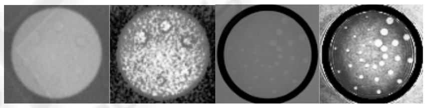
2.2.5 Low Contrast Detectability

In order to assess the ability of diagnostic equipment to produce images where low contrast objects are visible, procedures have been developed to detect the presence of low contrast image objects in image regions. For this purpose, an automated and a manual method were implemented. In the automated method a convolution-based approach is used for detecting the presence of low-contract objects. In several occasions, however, low contrast image objects are dominated by noise, causing failures to the automatic object detection algorithms. As an alternative, a manual method was implemented for low contrast object detection; in that case, the system performs histogram equalization in the region of interest and the user indicates the presence of low contrast objects in the enhanced image regions (Figure 9).



(a) (b) (c) (d)

Figure 8: Typical examples of distance measurements in CT (a and c) and US (b and d) images.



(a) (b) (c) (d)

Figure 9: Examples of image regions containing low contrast objects (a and c) and the corresponding histogram-equalized image regions (b and d).

3 SYSTEM IMPLEMENTATION

The database back-end has been implemented using the Microsoft Database Engine, Desktop Edition of SQL Server 200 including Service Pack 3. The database front-end has been implemented using Microsoft Visual Basic .NET 2003 on the .NET Framework v1.1. The front-end is a stand-alone application utilising the Windows Application Programming Interface (API) and connecting to the locally installed and running SQL server. The database has been created and maintained by using the 'server explorer' interface of the Microsoft Development Environment. Reports generated utilise Crystal Reports capabilities provided by the Microsoft Development Environment.

The image processing tool has been implemented using the Microsoft Visual C# .NET 2003 on the .NET Framework v1.1. Dedicated image processing routines have been implemented using the MATLAB R13 programming environment and the

MATLAB Image Processing Tool Box. We have exploited the MATLAB Com Builder to convert MATLAB applications (routines and functions) to Component Object Model (COM) objects. These objects can be immediately integrated with any COM-based application, such as Visual C# applications.

4 CONCLUSIONS

We have presented a custom-made system for managing quality control measurements and quality assurance program for diagnostic radiological imaging equipment. The proposed system uses an Image Processing Unit for image analysis, and a Database Management Unit to deposit all the data that relates to the Quality assurance process. Reports describing the performance of specific imaging units are generated based on the Data Management Unit.

The main value of this paper is the design of a system that supports the automation of the application of systematic quality assurance programs for diagnostic radiological imaging equipment in compliance with International Regulatory Committees and standards. Our study presents original work in the particular application domain since:

- There is support for the three main imaging modalities (MRI, CT, US)
- Measurements on images are carried out using dedicated image analysis algorithms rather than relying on manual measurements
- Measurements derived from images and user defined analyses are stored in a database so that quality assurance reports are automatically generated.

An important issue in the development of quality assurance programs is the reliability in reported measurements. In the case of the IPU, additional user visual checks served as an independent method of correctness of the software measurements. Additionally, for measurements that may fail in the case of using low image quality datasets, we have incorporated secondary methods that depend on human intervention.

The end result of this work is being used for re-enforcing the efforts of staging proper and effective Quality Assurance programs for medical imaging equipment, both at national and international level.

The system has been tested extensively on real images produced by MRI, CT and US scanners and the system performance has proved to be satisfactory. Since the system developed is unique it is not possible to compare it directly with other systems in this category. Initial feedback received by potential users of the system, proves the value of our approach for dealing effectively with QA control of medical images in real applications.

ACKNOWLEDGEMENTS

The work presented was supported by the Cyprus Research Promotion Foundation (project NEPRO-0204).

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