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Quality assessment in radiographic images

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Abstract—**The main purpose of this work is the assessment of quality performance of medical imaging systems by using objective image quality tests. To this aim, the influence of radiographic parameters has been investigated in order to reduce radiation dose to patients by assuring a good quality of the images.**

Keywords—Biomedical x-ray imaging, image quality, phantom, image contrast, radioation dose.

I. INTRODUCTION

Medical imaging systems are widely used in radiological diagnosis. Their main benefits are more accurate and faster exams, elimination of exploratory surgery, availability of post processing and computed aided detection, immediate images availability, and ability to store and/or transmit the images electronically [1], [2]. Opposite, the potential risk of associated ionization radiation exposure from medical imaging (such as Computed Tomography and digital radiography) must be considered in risk to benefit ratio assessment.

Growing concern expressed by Radiology Community about the increasing exposure to ionizing radiation, has led to investigate and develop dose suitable strategies able to deliver the lowest dose necessary to provide sufficient image quality required for extracting the desiderate details and diagnostic information.

Many studies have been proposed about the comparison of performance of an imaging system with another "reference" system to define the amount of possible dose reduction to provide the reference image quality. Using this approach, it is possible to optimize the system performance by means of an appropriate selection of technical parameters [3]-[6].

In this work, suitable and objective tests for image quality evaluation have been performed identifying the main parameters influencing the radiographic performance.

II. IMAGE QUALITY IN DIAGNOSTIC RADIOLOGY

The goal in optimizing image quality is to provide suitable image able to provide suitable contrast details with the minimum radiation dose to the patient.

There is a wide variety of approaches in the assessment of radiological image quality. The most applied techniques are based on the use of *Test Objects*, consisting on a set of standard objects able to provide objective information about the capability of imaging system under test to distinguish details at different contrast and resolution values under specific conditions.

Alternative methods for image quality evaluation use anthropomorphic phantoms based on suitable model for simulating the tissue composition of human body. Their aim should be to reproduce as closely as possible the behavior of x-ray energy after passing through structures of standard sized patients. These phantoms are more complex and expensive and are unlikely available in the departments of radiology.

The identification of an objective measurement index for image quality assessment is a very crucial issue which has led many researchers to develop and propose different quality metrics that effectiveness depends on image characteristics and specific applications.

In radiological diagnosis the image contrast is a very important factor which allows distinguishing the anatomical structures of interest from their surrounding and then it is basic for the correctness of the medical exams.

Another important factor is the resolution including the capability to distinguish different adjacent structures.

For these reasons the quality indexes taking into account resolution and contrast are mainly used in the radiological quality assessment.

III. MATERIALS AND METHOD

In the proposed study Test Objects were applied evaluate the performance of a digital radiographic system, KODAK DIRECTVIEW DR 7500, used for routine radiographies in Hospital "Casa Sollievo della Sofferenza" (San Giovanni Rotondo, Italy). The tested device is equipped with an *automatic exposure control* device (AEC) [7] which automatically sets the x-ray parameters as function of the selected beam potential and the patient's features. It has antiscatter grid placed close to the entrance surface of an image receptor for reducing the amount of scattered radiation reaching the receptor, according to the European guidelines for quality assurance in x-ray diagnosis [8].

The performance assessment of radiographic systems was carried out by means of TOR CDR (Leed Test Object) [9]. It was placed as close as possible to the receptor with a focus to receptor distance of 2 m, according to the Protocols for the assessment of Quality Image of Radiography Systems [10]. Then the phantom was exposed to x-rays generated by different tube potentials ranging in the typical values adopted in clinical use (110-120 kV) and the resulting image was processed by means of the available elaboration software AutoPIA (*Automatic Phantom Image Analysis*) [11].

TOR CDR consists on a plane sheet of perspex and metal including a set of standard objects designed to evaluate contrast and resolution.

Measurement tests for low contrast evaluating were performed by using an array of 17 circular objects placed on TOR CDR each having a diameter of 11 mm (with manufacturing uncertainty of 5%) and with different low contrast values varying in decreasing order. TABLE I. lists the nominal contrast values for all discs.

TABLE I. CONTRAST VALUES FOR DISCS WITH 11 MM DIAMETER

Disc Number	Contrast	Disk Number	Contrast
1	7.5%	10	1.5%
2	6.7%	11	1.3%
3	5.3%	12	1.1%
4	4.5%	13	0.9%
5	3.9%	14	0.7%
6	3.2%	15	0.5%
7	2.7%	16	0.3%
8	2.2%	17	0.2%
9	1.7%		

These values have been calculated as the intensity difference relative to the background for beam condition of 70 kV.

After the phantom is imaged, the elaboration software counts the number of circular details which are distinguished from background providing the threshold contrast for the radiographic device under test. This value depends on both the exposure conditions and the level of radiographic noise. Then, the elaboration software provides the value of *Contrast-to-Noise Ratio* (*CNR)* for each detected detail by means of the following expression:

$$CNR = \frac{\mu_d - \mu_b}{\sigma_b} \quad (1)$$

where μ_d and μ_b are the mean pixel value of detail and of the background, respectively, and σ_b is the standard deviation of pixel values of background [11].

Fig 1 shows a TOR CDR radiography obtained in the experimental tests.

Measurement test for spatial resolution evaluating were performed by means of a set of 30 groups of bar patterens each comprising 5 radio-opaque bars and 4 radiolucent spaces with different spatial frequencies varying in increasing order and expressed as line pair per unit of distance (lp./mm).

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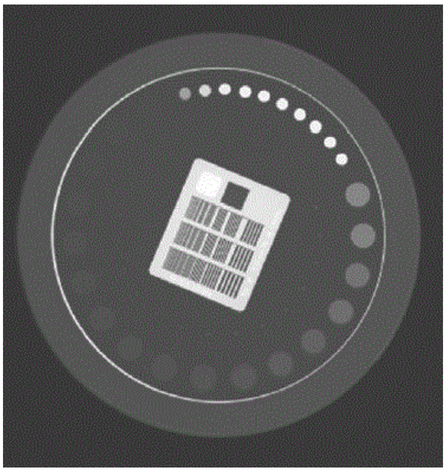

Figure 1 . Radiography of TOR CDR

Moreover, TABLE II. lists the spatial frequency values for all bar patterns.

After the test pattern is imaged, the elaboration software counts the number of bar patterns which are visible providing the highest spatial frequency that can be resolved by the radiographic device under test.

TABLE II. SPATIAL FREQUENCY VALUES FOR BAR PATTERNS

Group Number	Spatial freq. [lp./mm]	Group Number	Spatial freq. [lp./mm]
1	0.50	16	2.80
2	0.56	17	3.15
3	0.63	18	3.55
4	0.71	19	4.00
5	0.80	20	4.50
6	0.90	21	5.00
7	1.00	22	5.60
8	1.12	23	6.30
9	1.25	24	7.10
10	1.40	25	8.00
11	1.60	26	8.90
12	1.80	27	10.0
13	2.00	28	11.1
14	2.24	29	12.50
15	2.50	30	14.30

The resolution limit is an indicator of radiographic unsharpness which is fully specified by *Modulation Transfer Function* (*MTF*). Fundamentally, this parameter measures the contrast for different spatial frequencies and then empathizes the capability of distinguishing structures of different sizes. The elaborating software calculates the *MFT* for all resolved bar patterns by means of the following set of expressions based on the technique developed by Droegeand Morin [12]:

$$MTF(f)=\begin{cases}\dfrac{\pi\sqrt{2}}{4}\cdot\dfrac{M(f)}{M_0} & \text{if } f\geq f_c/3\\[2ex] \dfrac{\pi\sqrt{2}}{4M_0}\cdot\sqrt{M^2(f)-\dfrac{M^2(3f)}{9}-\dfrac{M^5(5f)}{25}-\dfrac{M^7(7f)}{49}} & \text{if } f\geq f_c/11\end{cases} \quad (2)$$

$$\begin{cases} M(f)=\sqrt{\sigma_D^2-N^2};\\ M_0=\left|\mu_r-\mu_b\right|\cdot\sqrt{\dfrac{n_r\cdot n_b}{n_r-n_b}};\\ N^2=\dfrac{\sigma_r^2+\sigma_b^2}{2}\end{cases}$$

where σ_D is the standard deviation of pixel values inside the bar pattern region (detail), μ_r and μ_b are the mean pixel value bars reference and background regions, respectively. In (2), σ_r and σ_b represent the standard deviation of pixels inside the bars reference and the background regions, respectively, and n_r and

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n_b are the number of pixels inside the bars reference and background regions. Finally, f_c is the spatial frequency of the bar pattern.

TABLE III. CNR VALUES FOR LOW CONTRAST TESTS

KODAK System		3 mAs	4 mAs	5 mAs	6 mAs	8 mAs
disc 11.0mm	Nominal contrast (%)	CNR	CNR	CNR	CNR	CNR
1	7,5	3,08	3,34	3,79	3,49	3,89
2	6,7	2,72	2,85	3,4	3,21	3,94
3	5,3	2,09	2,23	2,63	2,67	2,96
4	4,5	1,63	1,83	2,04	1,74	2,24
5	3,9	2,24	2,5	2,89	2,61	3,35
6	3,2	1,5	1,56	1,86	1,97	2,26
7	2,7	1,53	1,6	1,77	1,77	1,99
8	2,2	1,08	1,2	1,42	0,92	1,61
9	1,7	0,84	0,88	1,05	1,07	1,15
10	1,5	0,81	0,89	0,91	1,03	1,11
11	1,3	0,67	0,74	0,85	0,87	0,88
12	1,1	0,48	0,52	0,61	0,59	0,63

TABLE IV. MFT FOR RESOLUTION TESTS

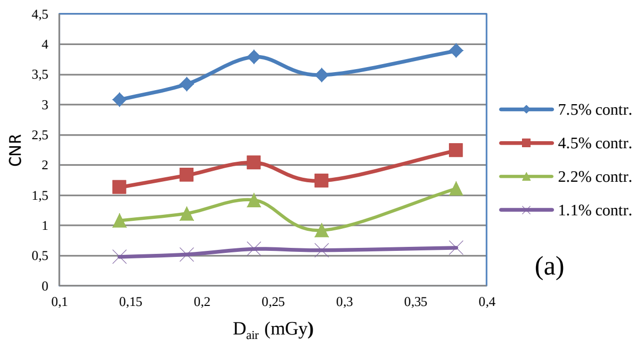
KODAK		3 mAs	4 mAs	5 mAs	6 mAs	8 mAs
BAR PATTERN	Sp. Freq. (lp./mm)	MTF	MTF	MTF	MTF	MTF
Bar Pattern 1	0,5	83,3	87,1	83,9	81,8	84,3
Bar Pattern 2	0,56	79,8	83	80,3	79,4	81,3
Bar Pattern 3	0,63	77,5	80,3	77,2	76,6	79
Bar Pattern 4	0,71	72,4	76	73,3	71,2	73,5
Bar Pattern 5	0,8	68,9	72	68,4	66,7	68,9
Bar Pattern 6	0,9	61,7	64,7	61,9	61,8	62,4
Bar Pattern 7	1	55,8	58,9	56,4	56	57,1
Bar Pattern 8	1,12	49,4	52,1	50,2	48,6	50,5
Bar Pattern 9	1,25	45	48,8	45,9	45,1	46,8
Bar Pattern 10	1,4	36,1	38	37,4	35,5	37,3
Bar Pattern 11	1,6	27,8	30,5	29,6	28,6	30
Bar Pattern 12	1,8	27,3	29,4	29,9	30,1	28,9
Bar Pattern 13	2	11	14,4	13	12,9	13,8

TABLE III. and TABLE IV. list the results of experimental tests, showing that the threshold contrast is 1.3% while the resolution limit is 2 pl./mm. These threshold values do not vary with the tube loading .

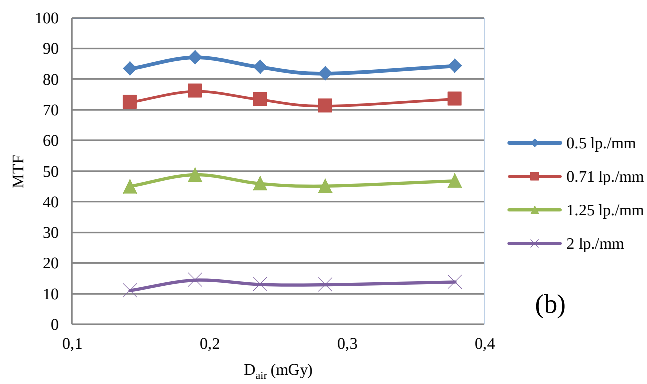
To evaluate the performance of Kodak system, different experimental tests have been carried out by setting five different values of the product of exposure time and tube current - often referred as the tube loading (Q) - and keeping constant the tube voltage at 125 kV, representing the most used value in chest digital radiographies.

Finally, to correlate the quality indexes with the radiation dose, the absorbed dose to air (D_{air}) [13] was measured using a RTI Piranha dosimeter [14] at a focus-to-detector distance of 2 m.

Then, experimental results allow studying the behavior of *CNR* and *MFT* as function of D_{air} so that to identify correlation between image quality indexes and radiographic parameters as shown in Figures 2.



(a)



(b)

Figure 2 Experimental behavior of CNR (a) and MFT (b) versus D_{air}

IV. CONCLUSION

In the proposed work, an analysis of imaging performance of digital radiographic system was presented.

Digital x-ray systems can induce an excessive dose to the patient in the medical examinations. With this premise, an in-depth analysis is advisable to identify the optimal technical parameters for reducing the levels exposure and assuring a suitable image quality. The experimental tests based on the use of Leed Test Object allow identifying the correlation between the radiation dose and the main radiographic parameters such as to obtain a fixed image contrast level.

Preliminary results were encouraging and seem to confirm the validity of the proposed idea.

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REFERENCES

[1] H. Hricak , D. J. Brenner , S. J. Adelstein, D. P. Frush, E. J. Hall, R. W. Howell, C. H. McCollough, F. A. Mettler, M. S. Pearce, O. H. Suleiman, J. H. Thrall, L. K. Wagner, "Managing Radiation Use in Medical Imaging: A Multifaceted Challenge", Radiology, vol. 258, no.3 pp.889-905, 2011.

[2] J.A Rowlands,. "Current advances and future trends in X-ray digital detectors for medical applications," IEEE Trans. on Instrumetation and Measurement, vol 47, no. 6 pp.1415–1418, December 1998.

[3] .F. Attivissimo, G. Cavone, A. M. L. Lanzolla, M. Spadavecchia, A Technique to Improve the Image Quality in Computer Tomography, IEEE Trans. on Instrumentation and Measurement, vol. 59, no. 5, May 2010, pp. 1251-1257.

[4] Z. Sun, C. Lin, Y.S. Tyan, K.H Ng, "Optimization of chestradiographic imaging parameters: a comparison of image quality and entrance skin dose for digital chest radiography systems," Clinical Imaging, vol. 36, no. 4, pp. 279-286, July-August 2012

[5] G. Andria, F. Attivissimo, A. Lanzolla,.G. Guglielmi, R. Terlizzi, "Dose Optimization in Chest Radiography: System and Model Characterization via Experimental Investigation", IEEE Transactions on Instrumentation and Measurement 2013.

[6] CJ Martin, "Optimization in general radiography", Biomedical Imaging and Intervention Journal, vol. 3, no. 2, pp. 1-18, April 2007.

[7] L. Bowden, R. Faulkner, C. Clancy, A. Gallagher, M. Devine, D. Gorman , G. O'Reilly, A. Dowling. "Doses under automatic exposure control (AEC) for direct digital radiographic (DDR) X-ray systems", Radiation Protection Dosimetry , vol 147, no 1-2, September 2011.

[8] "European protocol for the quality control of the physical and technical aspects ofmammography screening" European guidelines for quality assurance in breast cancer screening and diagnosis Fourth edition, 2006

[9] http://www.leedstestobjects.com/

[10] International Commission on Radiological Protection, Managing patient dose in digital radiology,Annal of ICRP, Pubblication 93, vol 34 , no. 1, pp. 1-73, 2004.

[11] http://autopia.cyberqual.it/index.php/AutoPIA

[12] R.T. Droege, R.L.Morin "A practical method to measure the MTF of CT scanners" Med Phys. vol 9, no.5, pp. 758-760, September-October 1982.

[13] E. Samei, "Performance of DigitalRadiographic Detectors:Quantification and assessment Methods" Advances in Digital Radiography: RSNA Categorical Course in Diagnostic Radiology Physics, pp 37–47, 2003.

[14] http://www.rti.se/products/piranha/